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IMPROVED AVIATION READINESS AND INVENTORY REDUCTIONS THROUGH REPAIR CYCLE TIME REDUCTIONS USING MODELING AND SIMULATION

by
Kevin F. Mooney
Guy R. Sanchez

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Principal Advisor: Keebom Kang
Associate Advisor: Donald R. Eaton

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Kevin F. Mooney
Lieutenant Commander, United States Navy
B.A., St. Edward's University, 1984
and
Guy R. Sanchez
Lieutenant Commander, United States Navy
B.A., Western Washington University, 1982

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December 1997

Authors: Kevin F. Mooney   Guy R. Sanchez

Approved by: Keebom Kang, Principal Advisor

Donald R. Eaton, Associate Advisor

Reuben T. Harris, Chairman
Department of Systems Management

ABSTRACT

This thesis research focuses on improved aviation readiness and reductions in pipeline inventory investment through repair Turn Around Time reductions related to the component repair processes internal to the Naval Aviation Depot (NADEP). Specific emphasis was given to the repair flow of a specific component from induction into the Depot for repair to the ultimate availability for sale to customers in a ready-for-issue status. The research models the current NADEP repair process flow and simulates enhancements to the process flow. These enhancements identify savings of over $52,000 in repair pipeline inventory investment for the candidate item. Our model and associated simulations provide NADEP with graphical and quantitative feedback which demonstrates the impact of process flow enhancements on repair Turn Around Time and Work in Process inventory efficiency.

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LIST OF ACRONYMS

A_o	Operational Availability
ACC	Aircraft Controlling Custodian
ADT	Administrative Delay Time
AIMS	Automated Induction Master Scheduler
AOG	Aircraft On Ground
AOM	Aircraft On Maintenance
AWP	Awaiting Parts
BREES	Barcoded Repairables Electronic Exchange Signature system
DLR	Depot Level Repairable
DoD	Department of Defense
DDA	Defense Data Access system
DDDC	Defense Distribution Depot, California
DMISA	Depot Maintenance Intraservice Support Agreement
DoN	Department of the Navy
DRC	Depot Repair Cycle
DRCT	Depot Repair Cycle Time
EMD	Engineering, Manufacturing and Development
FIC	Family Identification Code
FISC	Fleet and Industrial Supply Center
FMC	Full Mission Capable
HOS	Held Out of Service
ICP	Inventory Control Point
JPC	Job Planning Card
LDT	Logistics Delay Time
LMI	Logistics Management Institute
M	Mean Maintenance Time
M&S	Modeling & Simulation
MDR	Master Data Record
MDT	Mean Down Time
MOC	Maintenance Operations Center
MRP	Material Requirements Planning
MSA	Maximum Spares Allocation
MTBM	Mean Time Between Maintenance
MTM	Model-Test-Model
NADEP	Naval Aviation Depot
NAVAIR	Naval Air Systems Command
NAVAVNDEPOTOPSCEN	Naval Aviation Depot Operations Center
NAVICP	Naval Inventory Control Point
NEXUS	Naval Executive Universal System
NIMMS	NAVAIR Industrial Material Management System

NMC	Not Mission Capable
NMCS	Not Mission Capable Supply
NPS	Naval Postgraduate School
NRFI	Not Ready For Issue
NSN	National Stock Number
PC	Production Controller
P&E	Planner and Estimator
PMCS	Partial Mission Capable Supply
PNR	Part Need Rate
PROBE	Program Optimization and Budget Evaluation
PSM	Production Status MAPPER
QA	Quality Assurance
RFI	Ready For Issue
SIP	System Inventory Priority report
TAT	Turn Around Time
TEMSMO	Test & Evaluation, Modeling & Simulation Management Office
UA	United Airline
UADPS	Uniform Automated Data Processing System
UNREP	Underway Replenishment
WIP	Work In Process
WIPICS	Work In Process Inventory Control System

I. INTRODUCTION

A. BACKGROUND

Current Naval doctrine calls for control of the littoral region to ensure quick and efficient response to all threats or concerns of the National Command Authorities. Air supremacy through the employment of carrier battle groups and their associated aviation assets in the littoral region are a critical element of this policy. The state of Naval aviation readiness is directly linked to the availability of material for timely, cost efficient repair of aircraft currently in the Navy inventory. Availability of Ready for Issue (RFI) components to fleet aviation units is a critical component of the operations, maintenance, and supply support triad necessary for continued military air supremacy. The ability to manage the Not Ready for Issue (NRFI) repair process and its associated turn around time (TAT) can significantly influence system inventory investment levels, costs of repairs, and overall system responsiveness to fleet needs. With the current and projected austere budgetary climate, Cycle Time can have a strong impact on inventory availability and readiness.

Naval Inventory Control Point, Philadelphia (NAVICP-P) is tasked with inventory management responsibility for repair parts designated as aviation related repairables. Repair of approximately 600 of these aviation related components is accomplished by the Naval Aviation Depot (NADEP) maintenance facility at North Island, California. Timely repair of these components and their return to fleet inventories in an RFI status is essential for maintaining current and future readiness standards of naval aviation units.

In any manufacturing or repair environment, material flows, information flows, and processing techniques have a significant impact on the manufacture or repair cycle times. NADEP North Island has been in the component repair business for Naval aviation components for more than 70 years and its capacity and capabilities have varied greatly throughout its lifetime. It operates in a very dynamic environment with constant changes occurring in process inputs including required repair volumes, specific components, manpower availability, and funding levels. The dynamics of the component repair processes at NADEP North Island lend themselves to examination for potential improvements through the use of Modeling & Simulation (M&S) techniques.

Recent developments and growth occurring in the modeling of manufacturing processes and material flows have strong potential for influencing traditional repair cycle process flows for aviation components. The intent of a model is to emulate an actual system. Simulations (or experiments) can then be conducted on the model to determine the effects of altering model parameters on performance measures. Conducting experiments on NADEP's actual production system typically is not feasible. Moving or altering equipment is time-consuming and expensive. Buying the wrong new piece of equipment can be very expensive in both time and dollars. The ability to experiment on a representative model can yield information previously unattainable in any reasonable amount of time. M&S provides this ability and flexibility.

The modeling and simulation methodology used in this research is to (1) model the current component repair process flow and associated repair information, (2) simulate changes in the process flow, and (3) incorporate data from changes into the actual model. The objective of this research is to provide graphical and quantitative feedback to show the impact changes in the current process may have on Work in Process (WIP) inventory efficiency and cycle time. Potential yields in operational availability, productivity, pipeline inventory reductions, and internal material flows may result from the research conducted. The objective is to demonstrate a dynamic tool for use by the NADEP to optimize material flow and periodically evaluate changes in input mixes.

B. OBJECTIVE

Significant monetary savings can result from small incremental advances in management techniques. Cycle time reductions and process improvements can yield substantial pipeline inventory investment reductions. This research anticipates identifying areas for concentration on these measures for improvement. Identification of potential savings through modeling an individual item suggests that savings can be realized through the use of M&S in all repair processes. Given the austere budgetary environment the Navy expects to operate in over the coming decades use of any tools which lead to greater efficiencies is imperative.

C. RESEARCH QUESTIONS

Primary Research Questions:

- What are the potential impacts of process flow and layout changes on the current repair cycle time for components?

- What are the potential impacts of using modeling and simulation techniques on material flow and WIP inventory internal to the component repair processes at NADEP North Island?

- How does component repair information flow through the repair cycle and how is it used?

Background Questions:

- What is the current material induction process at NADEP North Island?

- What is the current method for computing component repair cycle time?

- What is the current material flow for a given component from induction to availability for sale?

- What methods are currently used to track work in process inventory?

- How are repair requirements for a given component determined?

- What are the mechanisms for information flow on individual components in WIP inventory?

- If a change to process flows occurs, how is the information used to determine its impact on Cycle Time?

- Are there redundant steps in the repair process and if so, what would be the impact on Cycle Time of eliminating redundancy?

- Do all levels of personnel have an understanding of Cycle Time flows and goals, and the impacts on fleet readiness and pipeline inventory requirements?

- Do divisions have access to WIP information and if so, how could it be used to improve Cycle Time?

- Is information on WIP available in real time, how is it tracked and provided to each division to allow planning of available resources, and measurement of actual component repair cycle time?

D. SCOPE, LIMITATIONS, AND ASSUMPTIONS

A single component repair process will be modeled from induction in an NRFI status to ultimate sale in RFI condition. NADEP represents a job-shop repair process environment, where the output varies from component to component and the activity includes a mix of jobs following different paths through a program network (Blanchard, 1992). Since no two jobs are alike, each job would require a unique model, thus we've selected one item that (1) is a readiness degrader, (2) has a value that can result in significant savings in inventory investment, and (3) entails a repair process that is not prohibitively complex in its number of paths.

The modeling process will demonstrate a representative general repair process flow for a given component repaired at NADEP North Island. Results of the model will be validated against actual component repair flows at North Island. Subsequent simulation results will be used for baseline comparisons with outputs from process analysis. The approximately 600 items which North Island has repair responsibility will be reviewed for fleet impact (i.e., readiness degraders), value and volume, and an impact candidate will be identified for use in the modeling process and analysis. Physical and informational flow diagrams and distributions associated with the candidate item will be collected for use in the modeling process. Simulation techniques will be used to conduct analysis of the component model. Upon completion, analysis results will be used to modify the original single item model to determine potential impacts of changes on Cycle time and WIP inventory levels. The component selected for evaluation is a *pitch trim hydraulic actuating valve motor* for an S-3 Viking fin stabilizer. The stock number is

6105-01-123-7973. The standard price for the motor is $6,310, the net price is $4,520, the procurement price is $3,680, and the cost to repair is $2,790.

E. ORGANIZATION OF STUDY

The methodology used in this thesis research will consist of the following steps:

- Conduct a literature search of books, magazine articles, CD-ROM systems, and other library information resources.
- Visit Naval Aviation Depot, North Island to observe operations, examine current practices, and collect data on current material flows.
- Visit United Airlines maintenance hub at San Francisco airport focusing efforts on examining the component repair facility to observe operations, examine industry practices and discuss process issues.
- Identify commercial software packages for simulation and modeling analysis.
- Prepare a baseline assessment to document the current repair processes at NADEP North Island.
- Identify measures of performance and performance criteria through visits.
- Model the process and conduct simulation experiments.
- Evaluate baseline model results with actual performance.
- Conduct layout analysis with candidate item.
- Prepare a comparison analysis.
- Make recommendations on findings.

F. ORGANIZATION OF THESIS

Our approach to researching Cycle Time and Inventory levels begins with an overview of Navy maintenance, the Depot Repair Cycle and the impact maintenance processes have on cycle time and inventory levels. We then introduce Modeling & Simulation concepts, how they are used, and potential benefits. This sets the groundwork for modeling NADEP's repair process. A review of actual repair process flows at NADEP North Island and United Airline's Maintenance Operations Center, and a comparison between the two organizations is followed by identification of an impact component used for the modeling and detailing the NADEP repair process. Covered next will be analysis of simulation results and reports on the potential benefits derived from multiple enhancements made to the base model. Finally, conclusions and recommendations will be provided for improving readiness and reducing inventory investment through application of modeling and simulation to cycle time reduction.

II. CYCLE TIME AND INVENTORY REDUCTION CONCEPTS

The Department of Defense Logistics Strategic Plan (1995) states that Operational requirements and unit readiness demand that support at the operational level be the prime focus of logistics. Building upon this focus, the Strategic Plan's Guiding Principles dictate that:

- weapon system availability and materiel readiness at unit level are of paramount importance
- the cost and "footprint" of logistics support must be reduced substantially without reducing readiness.

Supporting the focus and guiding principles, goal number one of the Strategic Plan is to reduce logistics cycle times. Each day of delayed response to the user represents millions of dollars in inventories waiting to be moved, repaired, delivered, stowed and used. The Plan's Objective *1.A.* for meeting this goal is "Reduce Logistics Response Time", as slow response times drive the need for increased inventory levels.

In examining the Depot maintenance process we will address these elements of the Logistics Strategic Plan, unit readiness, the logistics footprint, costs, and cycle time. We will begin this examination with a review of the Navy's maintenance concept and repair scheduling, components of cycle time, and cycle time's subsequent impact on operational availability and WIP inventory requirements.

A. MAINTENANCE CONCEPT

The Navy employs three levels of maintenance: Organizational (trouble shooting, replacement of parts on its own equipment), Intermediate (high volume, less in-depth repairs) and Depot (comparable skills and facilities to the original manufacturer), with Depot Level Maintenance being the most in-depth level of maintenance performed by the Navy. The Naval Air Systems Command (NAVAIR) currently operates three NADEP's within the continental United States and fleet repair sites in Italy and Japan. These facilities are located to support specific geographical area needs or desired product lines, and provide cradle to grave aviation depot maintenance services to NAVAIR and its customers. The NADEP's provide premier aviation maintenance, logistics, and engineering services. For over 50 years these industrial facilities have specialized in components, support equipment and ordnance equipment, as well as providing associated engineering, logistics and training support.

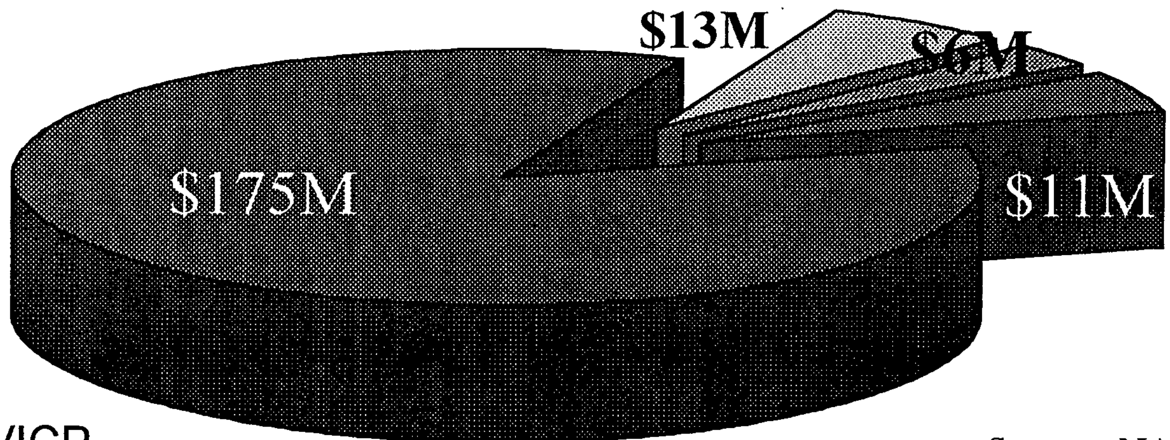
NADEP North Island's motto is "Productivity through quality ensures fleet readiness". This concept is achieved through a wide range of engineering, calibration, manufacturing, overhaul and repair services for numerous aircraft and ships. The mission of NADEP North Island is to serve as the production center concentrating on repair and modification of miscellaneous aircraft and associated components, and to serve as the West Coast Logistics, Program Management, and engineering services point. The Naval Aviation Maintenance Manual (OPNAV 4790.2F) defines the NADEP industrial functions as consisting of three general categories:

- Those involved in the manufacture of items and component parts otherwise not available.
- Those involved in support services functions which include professional engineering, technology, and calibration services.
- Those involved in the rework of existing aviation end items, systems, *components*, and support equipment. This includes *maintenance* and modification functions.

Maintenance functions are those functions required to maintain or restore the inherent designed service levels of performance, reliability, and material condition; they span complete rebuild through reclamation, refurbishment, overhaul, *repair*, replacement, adjustment, servicing, and replacement of system consumables. This research intends to analyze the repair process flow for repair of a specific component.

NADEP North Island operates in a very dynamic environment with constant changes occurring in process inputs, including required repair volumes, manpower availability, and funding levels. NADEP's Components Program supports a variety of programs: NAVICP-P inventories; installed components, Depot Maintenance Intraservice Support Agreement (DMISA), and other support (including modifications and engineering changes), (see Figures 2.1 and 2.2). In fiscal year 1997, component workload at North Island was valued at $213 million, comprised of overhaul/repair of 22,916 unique items and calibration of 31,362 unique items (see Figure 2.3).

NADEP North Island
Component Workload by Program FY-97

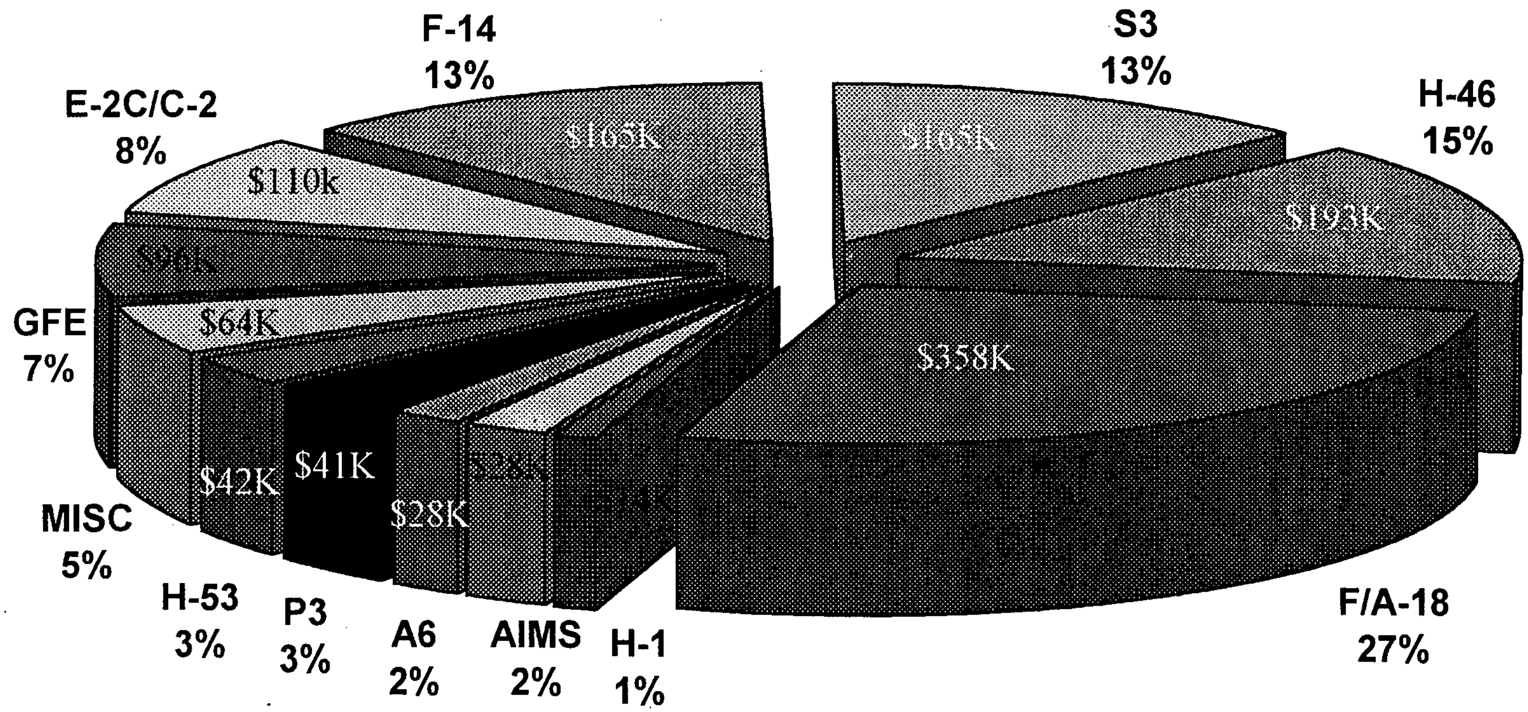


Source: NADEP North Island

FY 97 DOLLARS = $213M

Figure 2.1. Component Workload by Program

NADEP North Island
Component Workload by Application FY-97



Source: NADEP North Island

WORKLOAD BASE 1,375,000 MANHOURS

Figure 2.2. Component Workload by Application

NADEP North Island
Components Program Support:

Capability:

Overhaul/Repair of 22,916 Unique Items

Calibration of 31,362 Unique items

APPLICATIONS:

F/A-18	E-2	H-1	H-46	A-6	LM-2500
F-14	C-2	H-2	H-53	F-4	
S-3	A-4	H-3	H-60	T-2	

ORDNANCE COMMON AVIONICS SUPPORT EQUIPMENT

Source: NADEP North Island

Figure 2.3. Components Program Support

NAVICP-P is by far the biggest customer, with $175 million in FY97 for component workload supporting a variety of systems including: C-2, E-2C, S-3, H-46, F-14, and F/A 18. In all, NADEP North Island is responsible for providing repair support for over 600 different components for NAVICP-P. Navy requirements for repairable components, airborne equipment, and training devices are forecasted and developed by NAVICP. These requirements are generally based upon comparisons of the total stocks required to the quantity of serviceable items on hand and scheduled for receipt in the near future at the National Stock Number (NSN) level. This requirement determination is known as the stratification process.

Once the stratification process is complete, the requirements will be used to schedule NADEP component workload. For workload purposes, the rework of components is allocated man hours of work at each NADEP establishment. Component scheduling is a demand operation based on the immediate needs of the operating forces and is a coordinated function between NAVICP-P, the operating forces Aircraft Controlling Custodian (ACC) and the Naval Aviation Depot Operations Center (NAVAVNDEPOTOPSCEN). The scheduling of components for Depot level rework is accomplished by means of either Weekly Automated Repair Scheduling Program (B08) or the Component Repair Conference (formerly Level Schedule Conference).

The application operation B08 or program optimization and budget evaluation (PROBE) provides a schedule based on demand. NAVICP-P issues a weekly PROBE to NADEP with scheduling information on (1) Not mission capable supply/partial mission capable supply (NMCS/PMCS) special expedite candidates and priority 01 backorders,

(2) all other end use backorders, (3) stock backorders, planned requirements due within rework Depot Maintenance Turn Around Time (TAT), demand expected during rework TAT, and (4) planned requirements due within rework TAT plus 30 days demand forecast.

The Component Repair Conference schedules high demand, high dollar value aircraft components by means of periodic joint meetings which determine committed production schedules. The meetings are hosted by NAVICP-P and include attendees from several activities including North Island.

Industrial workload is scheduled on a quarterly basis by NAVAVNDEPOTOPSCEN for NADEP. These quarterly rework schedules, along with associated man-hour allocations, funding controls, and personnel targets are updated at fleet readiness support meetings, chaired by NAVAIR and attended by representatives from NADEP, NAVICP-P, and NAVAVNDEPOTOPSCEN. At these meetings, representatives review the quarterly schedules of assigned rework to ensure that the man hours available are sufficient to meet the scheduled requirements. When needed, interim meetings may be called in the event that workload contingencies occur or changes are required between the scheduled quarterly meetings.

The preceding workload scheduling process, balanced with NADEP's capacity, establishes the requirements basis for inducting material into NADEP's repair process. This induction process marks the beginning of the Depot Maintenance Turn-Around-Time portion of Depot Repair Cycle Time (DRCT).

B. DEPOT REPAIR CYCLE

This section will review the Depot Repair Cycle (DRC), Depot Repair Cycle Time (DRCT) and its elements. An unserviceable component beyond the repair capability of the organizational and/or intermediate level of maintenance and which is repaired at the depot level, is processed through the DRC. Per DODD 4140.1-R, the DRC begins when an unserviceable depot-level reparable (DLR) is determined beyond the repair capability of the organizational and/or intermediate maintenance activity. It ends when the item is restored to serviceable condition and is recorded on the inventory control point (ICP) records. Unserviceable items may remain in storage for extended times before being needed and transferred to depot maintenance. The DRCT excludes this time in storage. DRCT consists of Retrograde Time, Accumulation Time, Transfer Time and *Depot Maintenance Turn Around Time.*

Transfer Time to Maintenance begins with the date Defense Distribution Depot California (DDDC) receives the induction request to transfer a NRFI component to NADEP, continues through picking the component requested for induction, and ends with the receipt of the component in NADEP. Transfer from Maintenance begins when maintenance reports the availability of the serviceable asset, continues during the return to storage, and ends when NAVICP-P records the serviceable item. TAT begins the date an unserviceable item is received by NADEP and the change in Condition Code is processed from "F" to "M" on NAVICP's records, and ends on the date the component has been restored to RFI condition as reported by NADEP (TAT does not include awaiting parts time when in "G" condition).

Kiebler (1996) reported the following findings on DRCT:

- Based on the September 1995 *Budget Estimate Submissions,* the dollar weighted organic/contractor DRCT is 86.8 days, with a resultant repair cycle level investment requirement of $4.4 billion. The LMI estimates the <u>investment requirement would be decreased an average of $51 million for each day the DRCT is reduced</u>.

- Reductions of DRCT, do not result in an immediate proportional decrease in inventory and inventory investment. One-time acquisition and repair savings will be realized over a number of years and will vary by inventory control point, the size of the reduction, the asset position in relation to the requirements, and the mix of serviceable and unserviceable assets. Annual recurring inventory carrying cost reductions associated with the lower inventory will also be realized.

It is evident that NADEP plays an important role in the DRC and is a major contributor to DRCT. Referring to the Logistics Strategic Plan, we can foresee the potential impact in analyzing NADEP's TAT and its influence on the readiness and inventory investment goals and objectives of the plan.

C. CYCLE TIME IMPACT: OPERATIONAL AVAILABILITY & INVENTORY INVESTMENT

The overall length of the depot repair cycle is of vital importance for two basic reasons. First, timely depot repair of failed DLR's is essential to *operational readiness* and *sustainability*, and repair is typically the most responsive and least costly option for supporting customer requirements. Second, because of the high unit cost of DLR's, significant *inventory investment* results from the length of the depot repair cycle time. (Kiebler, 1991). The focus of this thesis is the Depot Maintenance TAT portion of DRCT. The goal is to reduce TAT and subsequently WIP inventory, as a means to (1) improve operational availability of aircraft, and (2) reduce inventory investment.

One of the major grading criteria for a naval aircraft squadron Commander is the availability or operational readiness of that Commander's squadron. Operational availability, a good measure of system readiness, is defined as the probability that a weapon system, when used under stated conditions in an actual operational environment, will operate satisfactorily when called upon. (Blanchard, 1992). Operational availability, A_o, is expressed mathematically as:

$$\mathbf{A_o = \quad MTBM \;\div\; (MTBM + MDT)}$$

Where:

- **MTBM** (Mean time between maintenance) = **1/MTBM$_p$ + MTBM$_c$** (or $1/(1/\lambda + 1/\mathrm{fpt})$ where λ is failure rate and fpt is preventive maintenance rate)
- **MDT** (maintenance down time) = **M + LDT + ADT** is total elapsed time required to repair and restore a system to full operating status.
    - **M** (mean active maintenance) = mean or average elapsed time required to perform scheduled (preventive) and unscheduled (corrective) maintenance.
    - **LDT** (logistics delay time) = maintenance downtime expended waiting for spare part to become available, waiting for transportation, waiting to use a maintenance facility, etc. A major element of MDT.
    - **ADT** (administrative delay time) = maintenance delayed for reasons of an administrative nature, i.e., personnel assignment, labor strike, etc.

Looking at the equation for A_o, we see that the availability of RFI spares affects MDT, the time it takes to repair and restore a system, in the denominator of the equation for A_o. By reducing the value of MDT, system A_o can be increased. To achieve desired improvements in A_o, we will focus on LDT, a sub-component of MDT, and the availability of spare components.

Three separate logistics support scenarios, can demonstrate that reducing repair TAT is an effective strategy for improving spares availability and consequently A_o. The third scenario shows that simply adding more spare components to the equation cannot cost effectively improve A_o.

- Scenario One- Setting the repair rate equal to the failure rate.
- Scenario Two- Setting the repair rate greater than the failure rate
- Scenario Three- Setting repair rate less than failure rate

Each scenario is examined using a spreadsheet decision support model that evaluates aviation fleet readiness. The model is designed for Intermediate level use, but can also be used to help understand the impact of TAT on WIP and RFI inventory quantities for various levels of A_o. Each scenario considers maintenance of one critical repairable item, without which an aircraft does not operate. (Kang, 1993).

An aircraft become not mission capable (NMC) due to either maintenance or supply problems. Thus, cost effective management of spare repairable components becomes crucial to maintaining an acceptable level of operational availability of aircraft. The spreadsheet model calculates aviation readiness by computing full mission capable (FMC) rates. It provides the operational availability of the aircraft, or the probability that an aircraft is ready to fly at any arbitrary time, i. e.,

$$\frac{\text{total number of aircraft - number of grounded aircraft}}{\text{total number of aircraft}}$$

The model is built with the following input and output parameters:

- Inputs: number of aircraft, component failure rate (λ) per aircraft, repair rate, number of spares, and the number of repair channels.
- Outputs: operational availability, number of aircraft grounded, average TAT for repair, and average WIP.

Figure 2.4 graphically illustrates the A_o curves the model provides for each scenario. We can recognize from this figure that increasing the number of spares under Scenario's One and Two will provide higher A_o, but, we also observe the diminishing marginal increase in A_o. Increasing the repair rate in Scenario Two clearly results in an increase in A_o at all levels of spares. Thus, for the same inventory investment level as Scenario One, an improvement in the repair rate directly translates into improved A_o. A different perspective is, if the target A_o has not changed, then the Navy's investment in inventory can be reduced without affecting A_o. Lastly, under Scenario Three, the model's repair rate has been decreased so that the aircraft failure rate is twice the repair rate. We observe that A_o remains a flat line, even when increasing numbers of spares. While throwing spares at the problem may slightly increase operational availability in the short run, in the long run, as the graph indicates, roughly 50% of the aircraft will be grounded regardless of the number of spares available.

The bottom line is, one cannot improve system operational availability without increasing the reliability of the critical component or reducing the repair time. In the three scenarios presented, additional investments in spare parts does not cost effectively improve system A_o.

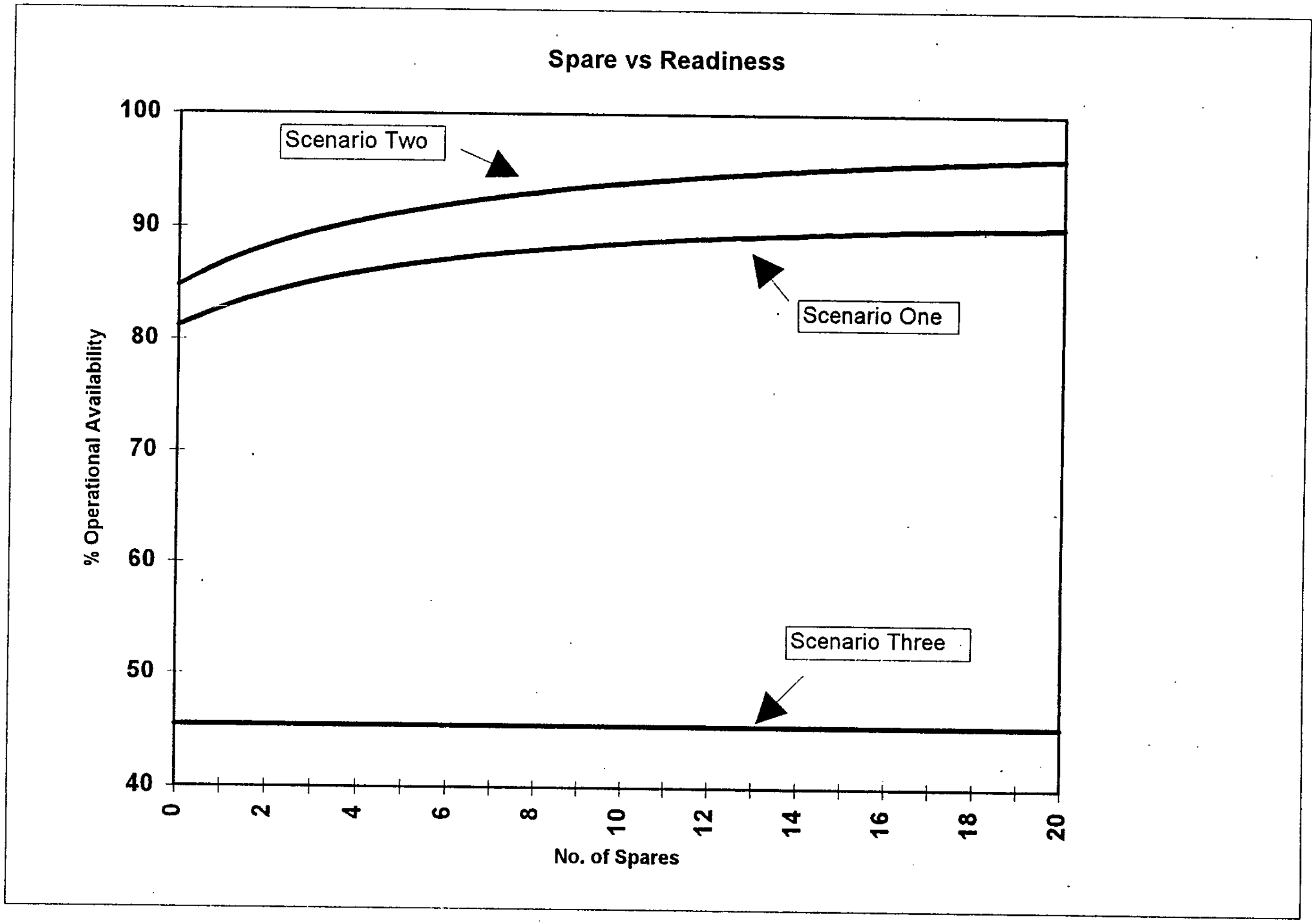


Figure 2.4. Impact of TAT on Operational Availability

Thus, DRCT reduction by focusing on NADEP TAT, can contribute to the goals and objectives of the Logistics Strategic Plan and contribute significant improvements in operational availability and reductions in inventory investment.

III. OVERVIEW OF MODELING PROCEDURES AND CONCEPTS

In exploring the benefits of using Modeling & Simulation (M&S) in a logistics environment it is important to address a number of questions from a logistics perspective. This chapter will examine such questions as what is M&S, why should M&S be used, and how can M&S be successfully applied in solving logistics concerns.

In the current and projected austere budgetary environment the Navy considers it vital to examine all current logistics business practices for efficiency and effectiveness. The current popularity wave of outsourcing and privatization potentially threatens DoD's core generic warfighting capabilities. While execution of many historically service related functions may prove more efficient by the private sector it is crucial that DoD ensure that its core warfighting logistic support functions be as efficient as possible in order to ensure they remain competitive with potential commercial competitors. Use of M&S techniques in logistics planning and execution can yield significant benefits and serve to ensure DoD and Navy core logistics capabilities remain competitive. (Navy Test & Evaluation, Modeling & Simulation Management Office (TEMSMO), 1997) This philosophy yields the Navy's M&S vision that using modeling and simulation to improve warfighting skills, make better analytical decisions and develop superior systems will help maintain the world's most powerful maritime forces for the joint force commanders.

In an attempt to reduce Depot Maintenance TAT and inventory investment, what would happen if NADEP was asked to allow experimentation with their actual physical repair processes? Change some things and see what happens? What would their response be? Simply experimenting with their physical system might be costly in terms of time, money and readiness, may be potentially dangerous or not follow required safety or quality assurance requirements, be disruptive to operations, or may be simply impossible.

Computer-based M&S provides a method and application to mimic the behavior of real systems - a stand-in - and allows for various experiments to be conducted that would otherwise not be feasible or possible. If the model is a valid representation of the system it attempts to depict, this allows for questions about what would happen in the system if changes are made and provides resulting data for analysis. It is important to recognize the many benefits of M&S over physical system changes (Cellier, 1991):

- A physical system may not be available. Often, simulations are used to determine whether a projected system should ever be built, so experimentation is out of the question.
- The experiment may be dangerous. Often, simulations are performed in order to find out whether the real experiment might "blow up," placing the experimenter and/or the equipment under danger of injury/damage or death/destruction.
- The cost of experimentation is too high. Often, simulations are used where real experiments are too expensive. The necessary measurement tools may not be available or are expensive to buy. It is possible that the system is used all the time and taking it "off-line" would involve unacceptable cost (for example, a power plant or a commercial airliner).
- The time requirements of the system are not compatible with those of the experimenter. Simulations allow us to speed up or slow down experiments at will.

Using computer modeling rather than the actual system is easier, cheaper and faster in getting answers by manipulating the parameters of the model. But M&S is much more than just building a model and conducting a statistical experiment. There is much to be learned at each step of a M&S project. People often study a system to measure its performance, improve its operation, or design it if it doesn't exist. Additionally, managers or controllers of a system might also like to have a readily available aid for day-to-day operations, help in deciding what to do in a factory if an important machine goes down or what to do if personnel constraints are changed. Kelton, Sadowski, and Sadowski (1998) have even found that some managers are not only interested in the simulation portion of M&S, but the fact that the modeling process provides them a comprehensive framework or flowchart that focuses attention on how their system currently works. More often than not, individuals have knowledge about specific pieces of their system but it's often difficult to find a comprehensive picture of the whole system. Also, analysts often find that the process of defining how the system itself works, provides great insight into what changes need to be made for improvements. After stating the benefits of M&S, what do we mean when we say Model and Simulation?

A model for a system and an experiment is anything to which the experiment can be applied in order to answer questions about the system (Cellier, 1991). This definition does not imply that a model is a computer program. However, for the purposes of this research, we shall concentrate on computer based models, specifically, the Arena Simulation system, a Microsoft Windows 95® based modeling and simulation package from Systems Modeling Corporation, Kelton, Sadowski and Sadowski (1998).

The definition of a model clearly qualifies any model to be called a system. We can cut a smaller portion out, a particular process, a specific component, and thereby generate a new model which is valid for a subset of the experiments for which the original model was valid. In this research we shall not attempt to model the entire NADEP system, but to model a process flow internal to the larger system. Use of the analysis techniques modeling provides will demonstrate the potential gains in modeling component repair process flows and performing simulations.

It is important we understand what simulation is. Simulation is the art and science of constructing a model and performing tests upon it to determine system. Computer simulation refers to methods for studying a wide variety of complex models of complex real world systems by numerical evaluation in software designed to imitate the system's operations or characteristics, often over time. Computer simulation deals with models of systems where a system is a facility or process, either actual or planned. (Cellier,1991) Some of examples of Navy systems which lend themselves to computer simulation are:

- An underway replenishment (UNREP) evolution with a servicing ship, customers, rigs and personnel;
- A breakfast line serving customers with chefs, menu choices and cooking times onboard Naval vessels;
- A Defense Depot receiving parts, stowing and issuing parts with personnel and handling equipment.
- A maritime relief operation transporting material from ship to shore and onward with transport devices, personnel, material and space for storage.

In the Navy's Weapons Systems Acquisition process, M&S reduces the time and cost of building, deploying, and modifying the Navy's weapons systems while increasing quality. Exploring alternative designs first with M&S helps demonstrate the value added to the warfighters and enables the decision to build or not to be made early in the concept exploration phase. M&S can be used to determine live testing requirements and reduce repetitive actual testing of systems. A Model-Test-Model (MTM) process reduces the risks throughout the life cycle of a system and provides a mechanism for demonstrating and validating system concepts and technologies. MTM facilitates the systems evolution from Concept Exploration through Engineering, Manufacturing, and Development (EMD), Production, Fielding and Operational Support. Additionally upgrades or modifications to systems can be accomplished more efficiently and effectively through the MTM philosophy process throughout a weapons systems life cycle.

Computer M&S has a myriad of applications but a key element in M&S is definition of the problem and its parameters. We must clearly define the system we intend to model and the current physical, monetary, and organizational constraints in which it resides. Only by doing so prior to experimenting with the model will we obtain simulation results that can be used as effective management tools. The most important strengths of simulation, but also ironically its most serious drawbacks, are the generality and ease of its applicability. It is relatively easy to utilize a simulation program, however, in order to use simulation intelligently, we must understand what we are doing. It is important that a physical separation exists between the *model description* on the one hand and the *experiment description* on the other. We want to be able to use our simulation tool in exactly the same way as we would use an instrument in a lab.

However, it is all too easy to apply an experiment to a model for which the model is not valid. An "experimental frame" must be established for the set of experiments for which the model is valid. When a simulation refers to that model, the actual experiment is then compared with the experimental frame of the model, and the execution of the simulation will only be examined for validity if the simulation experiment to be performed is established as belonging to the set of applicable experiments in the "framework". Simulations are rarely enlightening. In fact, running simulations is very similar to performing experiments in the lab. We usually need many experiments, before we can draw legitimate conclusions. Correspondingly, we need numerous repetitions of our simulations before we understand how our model behaves. While analytical techniques often provide an understanding as to how a model behaves under *arbitrary* experimental conditions, one simulation run tells us only how the model behaves under the one set of experimental conditions applied during the simulation run. Multiple simulations and iterations of various modifications of the NADEP component repair process will attempt to expose possible DRCT reductions and potential savings in pipeline inventory investment.

Here, it is important to quote yet another definition of the term "modeling". Modeling means the process of organizing knowledge about a given system. (Cellier, 1991) By performing experiments, we gather knowledge about a system. However, in the beginning, this knowledge is completely unstructured. As information is gathered about the current business practices at the NADEP and its relationship with NAVICP and Naval Air Systems Command (NAVAIR) an understanding of what are *cause* and what are *effect* are developed and we organize the knowledge gathered for the model experiment. While the scientist is happy to simply *observe* and *understand* the world, i.e., create a model of the world, the logistics engineer wants to *modify* it to his or her advantage. *Simulation* can then be used not only for analysis, but also for design or modification of a process.

Simulation is often not used alone but in an interplay with other analytical or semi-analytical techniques. The typical scenario of a scientific discovery is as follows:

- The scientist performs experiments on the real system to extract data (to gather knowledge).
- She or he then looks at the data, and postulates a number of hypotheses relating to the data.
- Simplifying assumptions help to make the data tractable by analytical techniques to test these hypotheses.
- A number of simulation runs with different experimental parameters are then performed to verify that the simplifying assumptions were justified.
- He or she performs the analysis of his or her system, verifies (or modifies) the hypotheses, and finally draws some conclusions.
- Finally, a number of simulation runs are executed to verify the conclusion

Typically, simulation is used to measure how the components in a system interact over time. A dynamic simulation model keeps track of the state of the system, records changes that affect system components, and uses a computer clock to simulate the progression of time.

Our model is an abstraction of a system, the component repair system, containing a component having unique characteristics and behaviors. The model incorporates logic to mimic the behaviors and interactions within the system and data that represent the characteristics of the system components. It presents the system graphically via animation and reports results as a set of statistics, such as utilization of personnel and equipment, length of queues, time parts spend in the system, etc. It is then our task to analyze these results and use our skill to make changes to the model, to redesign the system or recognize elements of the system that indicate capacity for reduced TAT.

The Department of the Navy (DoN), has undertaken a significant effort to improve effective and efficient use of M&S in support of the Navy's mission. Our use of ARENA will facilitate decision making in attempting to identify potential reductions in pipeline inventory requirements inherent to the component repair process flow at NADEP North Island. While our efforts will focus only on modeling the flow of a single item through the repair process, it is important to note that the model will represent only one of the more than 600 items for which NADEP North Island has repair responsibility. By identifying even modest savings through inventory reductions for this item we can clearly demonstrate potential benefits the modeling process can yield to the overall system.

IV. NADEP INDUCTION AND REPAIR PROCESS BUSINESS PRACTICES

A. INTRODUCTION

This chapter will examine the current NADEP business practices associated with the repairable component induction and repair process. We will look at the component repair process, examine some of the management information systems used, review work time standards versus actual work time, and survey some of the key documents in the process. As mentioned in Chapter I, NADEP's Component Production Program is a Job Shop process and for each component to be repaired there exists a Master Data Record (MDR), Appendix A. The MDR is a database that includes baseline data on components including repair time standards, survey factors, and all the possible steps that may be undertaken for repair of that specific component. Although typically not every task cataloged for a component is performed, every task from the MDR is printed out in the form of a Shop Order. Shop Orders may be one or two pages, encompassing a dozen requirements, or they may be over a hundred pages with several hundred potential steps. Although in a job shop environment there are a multitude of possible repair procedures, the general process will be described in three phases using our example component, the alternating motor.

Complementing the myriad repair steps for a component, NADEP has a variety of information systems and applications to process, extract, and transfer information. Throughout the process we will discuss some of the applicable systems and how they are used. Additionally, there are meetings and regular communications between NADEP personnel in various shops, Planner & Estimators (P&E) and with Fleet and Industrial Supply Center (FISC) support personnel and NAVICP-P personnel. Also, most of the people we spoke to were on several Process Action Teams intended to improve various production or manufacturing processes.

Figure 4.1 diagrams the repair process flow for the alternating motor, from the decision to induct for repair to its ultimate availability for sale and packaging in an RFI condition. We will follow the entire repair process in three stages: Phase I Induction to Transfer, Phase II Transfer and Shop Processing and Phase III Painting and Custody Exchange. Workload Inductions will be the opening step in Phase I.

B. PHASE I: INDUCTION TO TRANSFER

Per Chapter II, NADEP's repair schedule is driven by quarterly NAVICP-P requirements negotiated in advance, weekly PROBE's transmitted to NADEP, or components, based on history, that NADEP determines will be needed. Using the quarterly schedule, the P&E will balance requirements with personnel availability, shop capacity, and competing workload. He'll also stagger inductions to accommodate TAT and batch components when economies of scale can be attained. Weekly induction requirements are then loaded for the following week using the Automated Induction Master Scheduler (AIMS) via the Naval Executive Universal System (NEXUS). AIMS will spread the induction requests to DDDC over the five-day work period. When NAVICP-P requirements are received by a PROBE, the P&E will enter the requirement

NADEP North Island

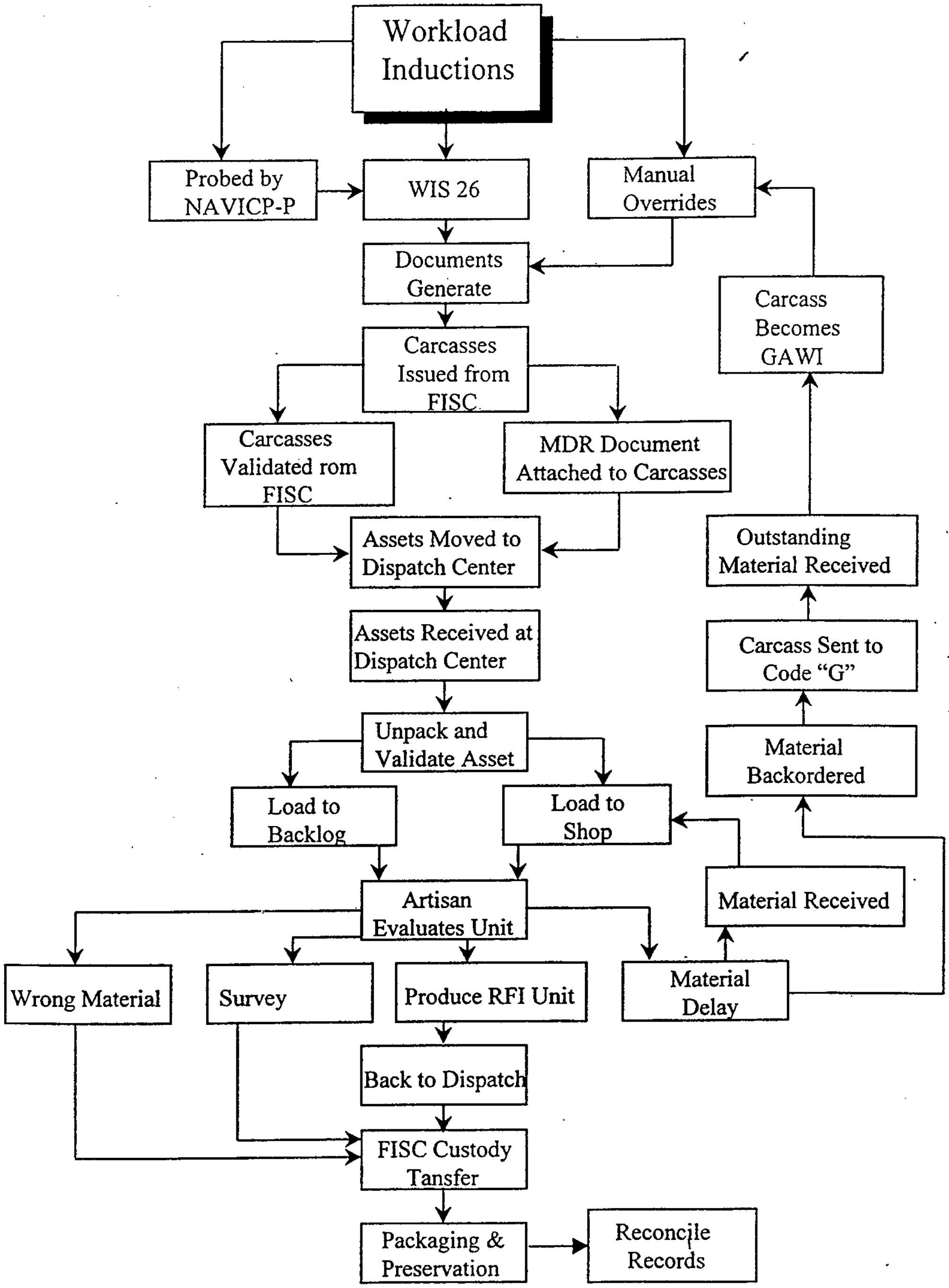


Figure 4.1 Component Repair Process

into Production Status Maintaining, Preparing, Producing Executive Reports (PSM) one day prior to document generation. Requirements submitted for induction will be processed and passed by PSM to FISC using the Defense Data Access (DDA) system.

Induction and production targets and actual quantities are monitored weekly using the Master Schedule Report from PSM. Watching the actual versus projected quantities inducted and produced, the P&E will address any deviations at weekly meetings with shop foremen. The P&E will make required induction changes for components leaving the system in "G" condition, when NRFI carcasses are not available or when components are surveyed. For either method of induction request, two barcoded Shop Order documents for each induction "job", a full-size job order document, Appendix B, and a smaller job card, are printed. These documents, usually several hundred a day, are then picked up from the Defense Automated Printing Service Detachment, building 90, by NADEP at approximately 5am of the second day of the process. A NADEP individual then removes any canceled items and is then required to individually match every remaining document and its associated job card and sort them in link number order. This same morning, P&E's have a last opportunity to edit the induction file through the Planner and Estimator Cancellation Program (PECAN) via PSM prior to being passed to FISC. Shop Orders are then delivered to the NADEP Central Induction Area located in building 662-3. The requirements are also passed to PSM as units scheduled.

The same day that the documents and job cards are picked up by NADEP, the induction requests are transmitted to FISC and DDDC to pull the material. DDDC pulls the material that evening from the available inventory of NRFI or "F" condition assets, and stages it at the NADEP Central Induction Area for transfer to NADEP representatives the following morning. Beginning at 7am on the morning of the third day, NADEP and DDDC personnel will jointly validate NRFI carcasses that are being transferred, attach documents and jointly log onto the Barcoded Repairables Electronic Exchange Signature (BREES) system. Using Intermec hand held scanners, the document barcode is scanned into BREES, completing the transaction, and NADEP takes custody of the NRFI carcass. It is important to note that this transaction marks the transfer of material to "M" condition and commences the *Depot Maintenance Turn Around Time* (TAT). The component status is then recorded by NADEP as "to shop" in the Work In Process Inventory Control System (WIPICS). By close of business, all induction transactions in BREES are then transferred electronically to PSM where the record has already been established.

C. PHASE II: TRANSFER AND SHOP PROCESSING

After NADEP has taken custody of the transferred material, they move it to the building dispatch center where it queues up for entry into the NADEP dispatch system. A dispatch center is essentially a shipping/receiving activity for handling material movements between NADEP buildings and work centers. The Components Program itself has shops spread among 27 buildings at NAS North Island. Each day trucks make facility-wide scheduled material movements between dispatch centers at 9:30am and 1:30pm. Additional movements throughout the day are made on an as needed basis. Components will then be picked up from building 662-3, either the same day or the following day, and be delivered to the dispatch center for the receiving shop. For our motor this is building 378. The motor will then be unpacked and validated by the center through PSM and moved to the shop area, day three or four. A transaction card from the component will be routed to the shop or the shop Production Controller (PC) will visit the dispatch center and pick up the cards. The PC will administratively receive incoming components into the shop's WIP inventory, and process them through WIPICS. The PC will track work destined for the shop, expedite routed parts, process all incoming and outgoing components in the management information system, and monitor the master production schedule. The PC will provide the transaction card to the Shop Foreman for assigning repair responsibility to an Artisan. The Foreman will verify the incoming workload, set priorities and identify and assign the next available Artisan trained to accomplish the specific work. The Foreman will place the card on a board under the Artisan's name so that the Artisan can visually determine that there is work awaiting his availability. Once the Artisan is available, he will pick the item up from the dispatch center and bring it back to his work center. The Artisan will then work through the applicable steps on the Job Order card. For the motor that we chose to study, there are a maximum of seven steps the Artisan takes.

- Evaluate the component
- Test
- Identify/Order/Waiting Parts
- Disassemble
- Repair

- Circle Maintenance Action Codes
- Final Test

It was previously mentioned that typically not all repair tasks listed on a Shop Order are performed. This applies to any component. At the evaluation step, the Artisan will examine the component and determine what optional steps on the Shop Order should be actually performed, whether by that Artisan or another shop. For a large Shop Order deck this may result in a significant number of repair steps eliminated and paperwork discarded. Again, any step listed on the MDR will print out on the Shop Order.

It is important to note that when the Artisan either finishes a step on the Shop Order document or ceases work for the day, he then enters his time and the step processed, identified by a shop and line number, into the Daily Employee Labor Transaction Analyzer (DELTA) system.

When parts are required, the Artisan orders material from the nearest FOCUS Store that, for the motor, is downstairs in building 378. The Artisan will physically go to the store and request required piece parts from the store's Material Handler. The Material Handler will complete the required documents and issue the requested parts if available. If required parts are not available at this or another FOCUS Store, the Artisan will then visit a nearby FISC Equipment Specialist, who prepares and submits orders to FISC for material not available at NADEP. The component is then given to the PC, who stores the component, the job is placed in delay status (awaiting parts, (AWP)) through WIPICS, and the Artisan begins a new Shop Order. All material requirements are passed to the NAVAIR Industrial Material Management System (NIMMS), identified by job order number, link number and line number. When material is received, responsibility for the job is loaded back to the shop via entry in WIPICS and the component is returned to the Artisan. If material is backordered and the estimated shipping date is over 45 days, the equipment specialist will seek alternative sources, procurement, manufacture, salvage or cannibalization. If no alternate source is found, transactions are entered into WIPICS and PSM, and the component is then coded as being in "G" condition. Depot TAT then stops and the component is returned to FISC for storage.

Once the Artisan has completed his final testing he will place the component on the "sell bench" to await a Quality Assurance (QA) inspector. The inspector, who will pass through shops several times a shift, will conduct the required inspection of the component and sign off the paperwork if it passes. The QA inspector will also randomly select items, five out of every 50, for testing. Having passed, the motor will next be processed by the PC via WIPICS, for transfer to the next step on the Shop Order - Painting. When sending a component to another shop, a metal tag is attached that includes the document link number, family identification code (FIC) and destination shop number. If items are small, then they are placed inside bags, and tape is attached to mark the destination shop location.

When the PC finishes his entry into WIPICS, the motor will be taken to the building dispatch center to await transportation to building 472 where the Paint Shop is located. This ends Phase II of the repair process.

D. PHASE III: PAINTING AND CUSTODY EXCHANGE

When processed through the dispatch center at building 472, the component will enter a queue to await painting. Once painted, it will then return to building 378 and the cognizant shop. Again, as it is leaving one shop for another, it will be entered into WIPICS. Back at building 378, the shop PC will process the motor for sale in WIPICS, the next step on the Shop Orders document. However, if the motor was inducted to meet the next quarter's schedule and is repaired this quarter it will not be processed. The PC cannot sell components out of quarter and it will be placed in a shop holding area until the next quarter.

If processed for this quarter, it will once more be routed to the dispatch center and await transportation to building 36 for custody transfer to FISC. At building 36, NADEP will process the component in WIPICS and then a joint NADEP/FISC entry is made into BREES, transferring custody and terminating *Depot Maintenance TAT*. By close of business, BREES will electronically update PSM for all daily transactions. Once FISC receives custody they will then forward the component to DDDC's Packaging and Preservation section, located in building 36, to protect the item for warehouse storage and ultimate issue to a customer.

E. MANAGEMENT INFORMATION/GOALS

Throughout the process we have touched on several of the computerized information systems that NADEP interacts with and we'll elaborate on systems that are used more often. PSM is normally used to provide more of an intermediate or macro level view of the repair process through many summary or detailed reports. PSM provides a variety of data including the number of items inducted, items completing repair and exchange, over-dues, overall TAT, specific shop WIP inventory and a general job status (in-work, delay status). Reports are produced through runs based on various parameters including job status, job order number, FIC, and final shop. Among its uses, it provides the P&E and shop foremen an overall view of inductions and repairs related to quarterly goals, and is a useful management tool for assessing goal attainment and the need to redirect resources or induct more assets. For material returning for custody exchange, a daily review is made from PSM and anything not received in 7 days initiates a search. Of approximately 300 items returned per day, it was estimated that roughly 1.5% may require follow-up. FISC's Uniform Automated Data Processing System (UADPS) also feeds into PSM, providing key information on whether an "F" condition asset is on hand at FISC to induct. If assets are not available to induct then a report is produced called the asset constraint and impediment review. This report is used to feed a twice-quarterly excel spreadsheet to NAVICP-P on carcass shortfalls.

As we've seen, a WIPICS entry is made each time a component enters or leaves a shop. Where PSM provides more of a wholesale view of inductions, WIPICS is used to register individual components at intervals throughout the process. WIPICS is batch processed and provides input data to maintain PSM. During our observations of the repair process, we did not see any WIPICS specific reports being utilized, although we were told that it can provide information to the PC on what is coming to that shop and can be used as a tracking aid.

It was mentioned that employees accessed the Daily Employee Labor Transaction Analyzer (DELTA) system at the end of the shift or upon completing a line number on the Shop Order. This makes the database information Artisan, component and repair step (or line number) specific. One of the advantages of Delta is that since time entered is associated with a repair line number, we were able to collect component repair time associated with specific repair steps. This provided the basis for computing contributions to actual TAT for a specific step and applying it to our simulation model. The Shop Foreman can also use this data to monitor individual employee output, contributions to TAT and the variability in process time. However, we did not see this data being used for TAT.

When assessing time to perform a job, we must distinguish between actual time versus time standards. NADEP bills for repair of a component based upon time standards established for a repair line and shop number. It does not bill for actual elapsed time required to repair a part. These standard times are resident in the MDR and print out on the Shop Order. Not every step on a Shop Order has a time standard assigned. NADEP only bills customers for actual repair operations. Other non-billable contributors to TAT include routing of components, administrative time, custody transfer, and awaiting parts or maintenance. Job standards for each repair step normally fall under one of four main categories for establishing the standards: A (time studies), B (work sampling study), C (Industrial Engineering Technician estimates), and D (NAVAIR Elemental Standard Data). Comparing the data we extracted from DELTA and the standards on the Shop Order for one component, we found there were significant differences in the actual recorded time versus standards for that repair operation. Part of this may be due to randomness of an Artisan's input into DELTA or the batching of parts for economy. In some shops a computer terminal is not conveniently located nearby and an Artisan may set finished components aside until others are complete in order to make one trip to the terminal. Differences may also arise from modifications to repair processes or transfer of repair responsibility from another activity.

NADEP was assigned repair responsibility for many new items when NADEP Alameda was closed. Subsequently, Alameda's standards were included on the MDR and North Island is finding that due to procedural or equipment differences many standards must be revised. Industrial Engineering Technicians will periodically review historical data averages on a component family to determine if a time standard requires adjustment.

Our observations from the shop level provided a view that understanding and aggressively reducing TAT was not a predominant organizational goal. Although several people said that TAT was constantly monitored, TAT appeared to be a static measurement that personnel must strive to meet. For most of the people, the quarterly Master Schedule was the dominant driving force. When assessing NADEP's productivity it was based on planned versus actual inductions and repairs.

A good example of the schedule focus was one shop keeping a large white-board prominently displayed for shop workers to view. The board lists components down the left side and across the top it lists scheduled quarterly requirements, cumulative repairs for weeks 1 through 13 of the quarter and goal status. Updated daily, this allows shop personnel to know at a glance how they are directly contributing to the shop and

NADEP's negotiated goals. The board is updated real time by the shop's internal accounting vice using a computer information system and is considered more accurate. Another aspect of the quarterly goal is the use of colored documents, a different color for each quarter. This allows personnel to recognize the relative priority of an item but also reinforces the focus on quarterly goals.

Again, one critical element we did not see aggressively targeted was TAT reduction and emphasis at all levels on how TAT affects the Navy, operational readiness, WIP and inventory investment. The information systems, PSM and WIPICS, were not user-friendly in trying to obtain and monitor TAT's for individual repair steps to use in evaluating the process for improvement. This contributes to TAT being viewed on an overall level, the sum of all the individual contributors. United Airlines also monitors TAT on an overall basis, but, in Chapter V we'll see that they also educate workers on TAT awareness and its critical impact on business practices and aggressively strive to reduce TAT to drive down inventory.

V. BUSINESS PRACTICES AT UNITED AIRLINES MAINTENANCE OPERATIONS CENTER

A. REPAIR PROCESS

Seeking to compare and contrast NADEP operations with a commercial depot facility, we toured the United Airlines (UA) Maintenance Operations Center (MOC), located in San Francisco International Airport. Spending time in the pneumatics repair section we acquired a general level of knowledge about UA's repair processes. We also toured some of the manufacturing shops and walked through the physical steps of a component's repair. UA also has overhaul facilities for its 737 fleet in Indianapolis, IN and DC10/747 fleets in Oakland, CA. Additionally, there are large facilities for line maintenance in Denver, Los Angeles, Chicago, New York and Hong Kong. However, the MOC is the primary UA component repair center, running two daily shifts repairing approximately 20,000 line items. Its component repair business is approximately 20% aircraft overhaul support and 80% repair for inventory replenishment. Unlike the Navy, UA effectively uses two levels of maintenance: Organizational or Line, and Depot levels.

UA classifies items sent to the depot for repair as recoverables, and assigns each item a Home Shop. If an item does not have a Home Shop, it's either not repairable or it's not something UA wants to repair. The Home Shop has responsibility for repair of a recoverable, whether it be by the shop itself or ultimate referral of an item to the Original Equipment Manufacturer (OEM) or a smaller vendor. Depending on the category of item (avionics, hydraulics, etcetera), the majority of items within a category could be worked by UA or by the OEM or another vendor. Each production shop designated as a Home Shop becomes responsible for system inventory level setting. The Home Shop is not responsible for inventory placement (geographical location) but the number the line inventory planner wants to have in the system.

UA's component repair process begins when a recoverable component fails and cannot be repaired by the line facility. NRFI items are immediately manifested as cargo on any available UA flight or shipped via Federal Express to the MOC Home Shop. The carcass will have a repair card attached to it and an induction tag identifying where it is to be stored. NRFI recoverables are stored in immediate physical proximity to the Home Shop. Repairs are initiated through a prioritized value assigned to the carcass and the availability of mechanics. The System Inventory Priority (SIP) report, Appendix C, is run shortly after midnight on a daily basis. The SIP Report is a listing of all items requiring repair no matter where they are in the cycle. Items are entered on the SIP report as soon as it's determined that the component must be sent to the MOC. The report includes the part number, noun name, criticality to flight code, daily target repair quantity, inventory quantity in serviceable status, stocking objective, number awaiting maintenance, estimation of required bench time, daily part need rate, and component support value. The component support value is the fundamental determination of repair priority. The higher the component support value, the greater the priority. The value is computed via an algorithm that weights the revenue generation of a route and the type of fleet asset, and the availability of additional spares. NRFI component status is updated daily on the SIP. As long as the component has not been inducted into a shop, the component support value may be constantly changing as RFI inventory quantities change, and criticality is re-computed. However, once an item enters the repair stream it flows through based on a First-in-First-out (FIFO) basis.

The Scheduler in a Home Shop keeps track of incoming recoverables and assigns work to available, qualified mechanics per the SIP priority or overrides the SIP report for emergent requirements. If a component requires expedited repair, the expediting is done by phone or computer messages - there are no additional priorities identified for moving a job other than First-In/First-Out (FIFO). Expedite requests that are not on the SIP come in from the Stores system - this means there is a real need right now, for either an aircraft on the ground (AOG) or aircraft on maintenance (AOM). The Scheduler will provide an estimated repair time back to the requester. If the time is not satisfactory the Stores system personnel then try to identify alternate sources, including other UA locations, other airlines or the OEM. The Scheduler, although assigned to a shop, actually works for a central inventory planning group.

After assignment by the Scheduler, the Mechanic will pick up the component from the shop NRFI storage area. If there is more than one component of the same family available for repair, the Mechanic should choose a component based on FIFO criteria. Sometimes, based on urgency of need, the Mechanic will choose the component having the quickest apparent turn around time. When issued from storage, the component status will be entered into the computer system as "in process". The Mechanic will then return with the component to his repair bench.

In preparation for repair, the Mechanic selects a repair procedures manual, located in the shop, for the item under repair. Taking it to his desk, he will follow the written steps in the back of the manual. There are some decision points in the manual that gives the Mechanic the option to perform tasks based on his evaluation, otherwise all steps in the manual must be performed. Individual repair procedures are not documented in the particular shop we visited, a component simply receives a repair/not repaired evaluation. Some shops, however, do have each step signed off, depending on the complexity of tasks, the requirement to route to other shops or required inspections. The repair manual is a combination of tasks that the OEM's manual says are required and modifications determined by UA's engineers. The majority are a mirror image of vendor's manual. The manual also includes descriptions of piece-parts that may be needed for repair.

If, during the repair process, a piece part is required the Mechanic checks the Stores System for availability. If the part is available then it is requested from stock via computer entry. It takes about one to one and a half hours for delivery to shop. If no parts are available the component is put in "held out of service" (HOS) status. Each shop has a parts expediter assigned to them, who may also handle more than one shop.

Repair manuals indicate if there are additional shops that the component or a sub-component must be routed to for completion of the applicable maintenance. If items must go to another shop for work, the Mechanic identifies and writes a repair number from the book on a repair tag and then physically places the part in a box for protection as it's routed. The component will be given to a shop clerk for processing. The clerk will look up the component class of inventory and print a Job Planning Card (JPC) with the routing/processes indicated by the Mechanic's repair number, and a barcoded tag for the item. The clerk will also annotate the quantity on the JPC and stamp it to show that the process has been set up. The JPC will be attached to the material, scanned into the computer, and then placed in the shop "out-station". The transaction will recorded in the receiving shop's Shop Floor Control system to provide the shop tracking and accountability. At each step a computer transaction is completed, the barcode scanned, starting from the clerk sending an item off, to the receiving shop entering receipt into the computer and again when sending it out of the shop.

The out-station storekeeper makes rounds to collect material for routing and takes all of the components to a central staging area downstairs. Components are then consolidated for outbound movement directly to the next shop, if in the same building, or to the central staging area if the shop is in another building. Components will normally take half a day to one day to arrive at the next shop for processing. The receiving shop will process it for repair on a First-In/First-Out basis. Prior to using a FIFO system, UA found everyone was trying to claim their items needed immediate attention causing delays in system flow. The FIFO system was initiated to standardize and smooth the process.

The receiving shop's Lead will make a printout several times a day of items coming to that shop. The Machinists, when they are ready for a job, then go to the next one in line on the printout, FIFO, and work it. At each stage in the repair process the JPC is then stamped to show completion of a step on the JPC. Once all steps on the JPC are completed, the component will be routed back to the Home Shop.

Once the component returns to the Home Shop and the Mechanic has finished with repairs, he will take a new induction tag with a yellow strip, signifying a component is RFI, and sign it off. In the Hydraulics shop when the Mechanic signs off the job this is the final evaluation of a components condition. There are no inspectors to provide a subsequent cursory review or perform testing. The Lead Mechanic will then initial the tag - this confirms that administrative steps were performed as required, and that a cursory check (safety wired, etcetera) has been completed. At this point the component is administratively entered into the system as RFI and will be shipped to a location based on a priority designated by the Stores system.

B. UA AND NADEP PRACTICES: COMPARE AND CONTRAST

Both NADEP and UA operate in a dynamic, job shop environment, where the repair processes differ between distinct components and especially vary among like components. This provides a significant variability and challenges in both organizations. However, several key contrasts exist between the organizations that affect UA's ability to possibly reduce some of the complications of the job shop process and improve TAT and reduce WIP.

An important difference between UA and the Navy is that the UA inventory managers are physically located with the repair shops and engineers, and report to the same manager as the component shop foremen. They find themselves working towards the same shared goals of keeping RFI inventory levels at prescribed quantities, meeting organizational cost objectives and TAT reductions. United Airlines employees have the same incentives and have a strong interrelationship for decision making and planning to achieve mutual goals and objectives.

Inventory planners at the MOC plan inventory levels for maintenance at the three bases, while line planners develop requirements for the line level. However, MOC base inventory planners also have responsibility for supporting all inventory assignments whether base or line locations. There are several inventory planning shops at the MOC, each one managing a group of components centered around particular shops. The planner for the pneumatics shop also has cognizance over hydraulic and electrical generator components.

A MOC inventory planner computes an overall system inventory level, called a maximum spares allocation (MSA) for his cognizant components. The MSA is based upon line requirements, base requirements, cycle time and daily part need rate. UA's cycle time is defined as the total time from when a recoverable is unserviceable coming off the aircraft until the component is again serviceable. This includes transit time to the repair facility and the total time in maintenance, awaiting maintenance, awaiting parts or awaiting induction. The daily part need rate (PNR) is the cumulative number of parts used over a period of time divided by the cumulative number of days during the period, both for the line and base requirements. The daily PNR is then multiplied by the planned cycle time to determine the number of components required to compensate for components in the repair process. This number is then added to a safety stock quantity and the line and base planned inventory levels to achieve a total system inventory quantity, the MSA.

As changes occur in line or base stock requirements, daily PNR or cycle time, inventory levels may need to be increased or reduced. MOC's inventory planners may be able to respond to increased requirements by working directly with the shops to reduce TAT. This close working relationship to reduce TAT is the basis for their goal in reducing inventory investment.

A second area of contrast is the documentation produced for the repair processes. In the NADEP repair process a complete Shop Order set is printed out for each component inducted. For some items this may mean a hundred printed pages composed of several hundred steps. At the evaluation step, some tasks may be deleted, sometimes resulting in the removal of several pages from the Shop order.

UA simply inducts and routes components using induction tags and JPC's listing only selected tasks required outside the Home Shop. The repair manual in the shop provides the steps required for each component. This negates the requirement for default volume printing of repair steps, especially for tasks that may not be accomplished.

The third contrasting aspect between the Navy's and UA's business is in the Navy's depot repair cycle, where NRFI components may be routed through several locations before eventually being sent to a FISC/DDD for storage. Currently there is an immense number of components residing in storage that may have been there for a long time, and which have no solid assignment for repair. Components may languish in storage for years until a repair need is established or it is removed for disposal. With UA, component turnover is critical to its goal of reducing investment in inventory. NRFI components in the repair cycle are all prioritized for induction and physically reside in the

Home Shop's storage area. There is complete inventory and repair visibility over every component by all management levels. There is not a question of whether an item will enter the MOC repair cycle but what priority it has in competing with other NRFI components for repair capacity.

Additionally, when measuring repair cycle time, the Navy does not include the time a component is in storage awaiting an induction request. For UA, cycle time starts when it is determined that the recoverable must be sent to the MOC and includes all the time elapsed until it is reported as RFI. This time is readily and explicitly visible to inventory and repair personnel. Two critical decisions to UA's repair effort was to go to FIFO scheduling in shop routing, and to reduce its backlog of components awaiting maintenance. FIFO scheduling allowed them to standardize the processing of components routed to the shops and may have impacted TAT. Reviewing the backlog of components awaiting repair, UA determined that there was too much idle NRFI material having no effect on RFI inventory levels and fleet readiness. Basically, wasted investments providing no return. By slowly reducing these excess components they have freed up funds, reduced the number of components in storage and reduced TAT. Shop Leads indicate that the reduction in NRFI inventory has significantly reduced waiting queues and sped up their processes.

UA has a very visible objective of reducing TAT. From the Inventory Planners to the Shop Foremen and Mechanics, TAT reduction is viewed as a necessity for reducing costs and remaining competitive. UA explicitly educates their personnel on the relationship between TAT and inventory investment and the need to improve TAT and reduce the money invested in inventory. There are periodic meetings with mechanics to explore the feasibility of reducing cycle time and reminders of the importance of TAT on inventory reduction are even seen on the computer screen savers throughout the MOC. Although the Planners, Foremen and Mechanics do not receive a direct incentive for reducing TAT, UA is 51% owner operated and has an employee stock option plan. Thus, keeping the company profitable does create a monetary incentive and affects job security. (Profit sharing of upper-level management is also an important incentive.)

UA, however, does keep track of cycle time in the same manner as the Navy, as a system aggregate vice tracking cycle time for components of the process. UA told us that sometimes engineers may look at specific pieces of the process, otherwise it is a matter of encouraging personnel to improve their portion of TAT. UA believes this approach will work because they have significantly reduced NRFI inventory backlog and improvements in any area of TAT will affect overall TAT.

It seems to be easy to make direct comparisons between UA and NADEP, and contrast business practices, however, we must recognize that there are legitimate differences in the missions, goals and objectives and structure of UA and the Navy. In contrasting the two organizations the goal is to reveal possible commercial practices that could be evaluated for application to the NADEP. In the Navy's austere budget climate, innovations that once seemed inappropriate may now be the feasible practices that allow us to operate more efficiently. In Chapters 6-8 we will model NADEP's current repair processes for the alternating motor, FIC BYFA, simulate changes in the process and analyze the impacts those changes have on TAT and WIP.

VI. IDENTIFICATION OF A MODELING CANDIDATE

Identifying a suitable candidate for modeling requires that an item's value, frequency of repair, and criticality to fleet needs all be examined. An ideal candidate must possess the right attributes and also lend itself to the modeling process. The basic intent of this research is to identify an "impact" candidate that can clearly demonstrate the potential benefits of using M&S in the logistics arena. Specifically, to demonstrate process changes that could result in a reduction of the inventory required in the repair pipeline and the resulting investment savings from reductions in this pipeline inventory. Determination of an appropriate candidate for this purpose was simplified through data collection efforts with NADEP North Island and the NAVICP-P.

Figure 6.1 is an excerpt from NADEP North Island's Production Status information system. The information presented is a report identifying the items identified as fleet readiness degraders for the 4th quarter of fiscal year 1997. A readiness degrader is defined as any item that, due to its shortness of supply in RFI condition, has caused fleet aviation readiness to be degraded in some fashion.

In addition to providing the data necessary for selecting an appropriate candidate, Figure 6.1 provides current data on the number of assets currently in "F" and "G" conditions. Assets in "F" condition are in an NRFI status awaiting induction into the repair cycle. Items in "G" condition are those which were inducted for repair but were removed from the repair cycle due to lack of availability of the material needed to complete repairs. Analysis of this data as percentages of total system assets and examination of the

FIC	SER	RSHOP	NOMEN	AVG MDR TAT	AVG ACT TAT	WKLD STD	QTY F	QTY G	QTR REQ	REV QTR REQ	CUM IND REQ	CUM IND ACT	NADEP CUM PROD REQ	NADEP CUM PROD ACT	SHOP CUM PROD REQ	SHOP CUM PROD ACT	QTY M
3JEA	3833	93208	FAIRING,	48	35	84.7	0	36	33	S	34	34	28	28	28	28	6
4GYA	3819	93806	ACTUATOR,	23	17	16.3	0	3	9	S	11	11	7	7	9	9	4
5CGA	3783	93806	ACTUATOR,	22	42	47.4	1	8	5	S	13	13	4	4	4	4	9
5VEA	3717	93808	CONTROL B	20	25	29	0	1	5	S14	15	15	14	14	15	15	1
6DBA	3825	93806	ACTUATOR	20	30	18.7	0	1	31	S26	30	30	20	20	21	21	10
6FNA	3720	93301	PROBE ASS	12	0	25.3	3	16	14	S0	5	5	0	0	0	0	5
71H4	2479	93303	GEARBX FL	1	42	21.1	29	51	0	E4	8	8	4	4	4	4	4
A2CA	A2CA	93305	AXLE LDG R	54	120	31.72	23	0	3	V3	19	19	2	2	4	4	17
A3UA	A3UA	93303	RESERVOIR	18	65	34	4	6	15	V15	22	22	8	8	8	8	14
AG7A	1436	93304	SH ABS ML	42	52	45	56	0	62	V	75	75	27	27	27	27	48
APBA	APBA	93209	RUDDER AIR	53	86	50.25	20	0	4	V4	6	6	2	2	2	2	4
AW4A	AW4A	93301	VALVE,GAT	16	37	5.1	9	5	15	S15	29	29	11	11	12	12	18
AYXA	AYXA	93208	ELEVATOR,	49	33	70	0	6	0	S7	3	3	1	1	1	1	2
B04A	B04A	93302	VALVE SKID	12	0	13.27	59	0	0	V30	0	0	0	0	0	0	0
BA2A	1553	93503	ENCODER-D	23	0	12.7	1	32	17	V2	11	11	0	0	3	3	11
BHQA	1557	93208	AILERON R	63	67	42	10	7	8	V	10	10	5	5	5	5	5
BS6A	1437	93305	STRUT	29	104	161.1	20	12	10	V	10	10	4	4	4	4	6
BYFA	3711	93806	MOTOR, AL	19	26	9.9	121	38	70	S	97	97	70	70	70	70	27
C2UA	1706	93303	CYL ACT	44	102	6	6	2	0	V	1	1	1	1	1	1	0
C79A	1697	93209	FLAP TE L	96	105	129.6	0	4	4	V	3	3	2	2	2	2	1
C7WA	1698	93209	FLAP TE R	96	0	117.2	2	8	10	V	6	6	0	0	0	0	6
CTEA	1477	93304	U JOINT	25	42	6.5	23	0	32	V	59	59	23	23	23	23	36
D78A	D78A	93808	CONTROL	26	13	7.13	4	12	2	V2	2	2	1	1	1	1	1
DKPA	1727	93207	FLAP SHRD	53	52	45.1	12	2	6	V	9	9	2	2	2	2	7
DWWA	1482	93301	HEAT EXCH	31	64	17.2	15	0	6	V9	24	24	9	9	9	9	15
E1RA	2454	93303	MOTOR HYD	36	44	18.7	10	36	40	E30	58	58	28	28	31	31	30
E251	2518	93303	VALVE-SEL	23	79	7.2	0	0	3	E	6	6	2	2	2	2	4
E2UA	1544	93209	CANOPY, MO	63	0	152.6	0	1	2	V	3	3	0	0	2	2	3
EBLA	1558	93208	AILERON L	61	44	77.7	4	18	10	V	9	9	4	4	5	5	5
F9GA	F9GA	93305	SWVL BRACE	27	36	4.46	21	0	15	V15	21	21	13	13	15	15	8
FPUA	1463	93208	AILERON	63	44	79.8	10	39	17	V	21	21	10	10	11	11	11
FQAA	1464	93208	AILERON	63	52	79.8	9	47	15	V	17	17	4	4	4	4	13
FRSA	3860	93301	CSD	48	73	66.3	5	85	22	S	57	57	12	12	20	20	45

Figure 6.1. Production Status Report

inventories in the repair pipeline through M&S techniques will be the focus of the remainder of this research.

The item highlighted in bold print in Figure 6.1, identified as FIC: BYFA, is an alternating motor used on an S-3 hydraulic actuating valve. The data presented in Figure 6.1 led to identification of BYFA as an ideal candidate for modeling. BYFA, currently valued at $6,310 per unit, has a quarterly induction requirement of 70 units, meeting the volume requirements, and is currently a readiness degrader for the S-3 fleet. Modifications to the repair process, identified using M&S, resulting in incremental decreases in unit volume in the repair pipeline can potentially yield inventory investment savings of $6,310 each.

VII. MODELING OF REPAIR FLOWS

The modeling process begins with a comprehensive identification of the system and components to be modeled. In order to ensure each aspect of the repair process is adequately incorporated into the model, it is important that the repair process is diagrammed using flow chart techniques. Appendix D diagrams the repair process flow for the candidate item, BYFA. This appendix illustrates the current flow the item passes through from the decision to induct for repair to its ultimate availability for sale in an RFI packaged condition. Without first visually illustrating the process in this fashion and validating each step, aspects critical t the overall process could be missed and the model would not function as a useful tool for critical analysis. This chapter, utilizing Appendix D as a framework, will examine each step in the repair process and the rationale for assigning statistical distributions for the repair processes. For ease of observance, these distributions have been compiled into tabular form as Appendix E. Each of these distributions and how they were determined will be discussed in turn throughout the remainder of this chapter.

The model will be examined as a series of steps or phases of the repair process. Each phase ends with the component requiring transport to the next phase through the base dispatch center network.

A. PHASE I: TRANSFER TO INDUCTION

This transfer to induction process is composed of:

- NADEP's initial induction request for an NRFI asset into the repair process,
- DDDC's pulling and staging the material and,
- NADEP's receipt of the material and matching of associated paperwork.

As Chapter IV detailed, a quarterly induction quantity for any given component is determined by a number of factors. Primarily though, level schedule negotiations are conducted between NAVICP-P and NADEP for induction levels. In modeling terms, the rate of induction requests throughout the order is designated the "arrival rate." The models arrival rate has been calculated as the quarterly negotiated quota for the item divided by the number of days in the quarter, 90. This number is then expressed as a fixed number of hours between inductions, stabilizing the models quarterly arrivals at the predetermined quota rate. No variance has been introduced into the arrival rate for the item to ensure consistency with actual arrival rates. Additionally, it is assumed that the NRFI asset is available for induction upon request by the NADEP.

Once the induction request is received by the DDDC, the component is pulled from the available inventory of NRFI or "F" condition assets and staged for custody transfer to the NADEP. DDDC receives induction requests daily and holds them in suspense until 9am the following work day. DDDC pulls "F" condition assets on an 11am - 7:30pm shift and stages them for transfer to the NADEP the next morning at 7am. Based on conversations with NADEP personnel, it has been determined that the DDDC pull & stage step, approximates a Normal distribution with a mean of 36 minutes and a standard deviation of 7 minutes. Expressed in hours as, N (.6,.12) hours. By scheduling the availability of the three DDDC personnel, the model restricts operation of the pull & stage function to the specified 11am - 7:30pm five-day work week schedule. Any item which DDDC personnel pull is held in a queue and released to NADEP for processing during NADEP's next scheduled shift, the next morning at 7am.

Phase I of the repair process is completed when NADEP accepts custody of the material and matches it with the applicable paperwork. Each item is processed individually but all must wait in a queue with other NRFI assets for processing. Discussions with NADEP personnel responsible for conducting such transfers indicate an average time for processing an item, including its queue time, to be 30 minutes. For modeling purposes a normal distribution of N (.5, .1) has been assigned. Just as the DDDC personnel were restricted to an 8 hour, 5 day work week, so are the NADEP receiving personnel. The model restricts them to a 7am to 3:30pm work day, the normal shift for all NADEP personnel.

NADEP having accepted custody of the material and matched the associated paperwork, sends the material into the NADEP dispatch system, the routing activity between repair locations. Currently, trucks make facility-wide scheduled material movements at 9:30am and 1:30pm Monday - Friday. Additional movements throughout the day are on an as needed basis. The model has been structured to reflect these limitations on material movement. The time requirements for a material movement between dispatch centers has been established as following a Triangular distribution with minimum, average, and maximum time as 1, 5, and 18 hours respectively. The rationale for assigning this distribution in the model is that an item could be ready for transport within approximately an hour of the 9:30am movement, could be processed after 9:30am and have to wait for the 1:30pm transport, or may miss both daily transports and have to wait up to 18 hours for the next morning's 9:30am transport.

B. PHASE II: SHOP PROCESSING

Having passed through the transportation network and arrived at the responsible work centers location (building 378 for our candidate), the following steps must be accomplished:

- Dispatch center processing
- Receipt into the shops WIP inventory by the shop Production Controller (PC)
- Assignment of an artisan for repair or loading to backlog waiting for artisan assignment
- Artisans physical pick up of the material from the dispatch center and return it to his work center (shop)
- Placement of the item on *test bench* to determine fault
- Determine/order materials needed for repairs
- Disassemble Item
- *Conduct Repair*
- Document repair action
- Conduct *Final Testing*
- Conduct Quality Assurance Inspection
- Processing for Transport

While the actual repair procedures are not the focus of this research, it is important for our model of the process to capture the time actually spent on each step of the repair. Data collection methods for times associated with each of the shop processing steps ranged from heuristic methods to collecting and compiling historical data associated with Artisan time on individual steps. Of the 12 steps which compose Phase II, only the *test bench, conduct repair, and final testing* steps had time distributions determined through actual data collection. The time associated with each step, as indicated next to the step, are a compilation of data extracted from the NADEP DELTA information system explained in Chapter IV. Appendix F is a compilation of the actual times Artisans spent on these three repair steps over a six month period. Average values and the standard deviation for each data set are calculated assuming a normal distribution for each data set.

For each of the remaining nine steps in Phase II, we have assigned process times determined through interviews with NADEP personnel involved with the individual process steps. The distribution types used in modeling the repair process were determined by using the interview data. As indicated earlier, Appendix E provides all distribution times in a tabular form. As the component emerges from the repair process it passes through *quality assurance.* Upon passing it is processed for routing to another shop and is delivered to the dispatch center for transport.

C. PHASE III: PAINTING

The item is now routed to building 472, the manufacturing section, for completion of the *painting* process. Building 472 houses a variety of manufacturing activities for the NADEP. While times associated with the flow of components through NADEP's

Manufacturing Section is also not the focus of this research, the time spent inside building 472 is a critical element of the model. For the model, times associated with the steps inherent to the painting process have been combined into a single time spent in building 472. Items requiring paint are routed and processed through building 472 dispatch center and end up in the paint shop queue. The paint shop will routinely process all items in its queue during a single work day. However, an item must dry and cure before being ready for transfer to its next step in the repair process. This injects some uncertainty into the process and items can, at times, take significantly longer than one day to complete paint. For this reason, in the model a Triangular distribution has been assigned to *painting* with minimum, mode, and maximum times of 18, 24, and 88 hours, respectively.

D. PHASE IV: SALE PROCESSING

The item then transitions into Phase IV, back through the dispatch network on a return trip to the cognizant repair shop in building 378. Once again, the route time for the return trip to building 378 is TRIA(1,5,18). The building 378 dispatch center processing has not changed and is N(1.5,.33) inbound and outbound. The sole purpose for the items return to building 378 is *sale processing.* The time associated with this step is negligible but none the less contributes to TAT. Sale processing by the shop PC follows a N(1,.2) distribution.

E. PHASE V: CUSTODY TRANSFER TO STORAGE

Phase V, the final phase of the process and the model, includes:

- Transfer of custody, in an RFI condition, back to DDDC,

- Packaging and Preservation of the item, and
- Routing to a DDDC warehouse for stocking.

Step one of Phase V is the point where actual repair TAT and WIP are measured and the place where the model ceases to track TAT and WIP as well. It was useful however to include packaging, preservation, and routing to the ultimate sale point in the model development to help illustrate the entire return to RFI stock condition cycle. Distributions for each of these Phase V steps were determined once again through the interview process.

Distributions associated with each step in a computer-based model are critical elements that must be thoroughly researched to ensure the model replicates the actual system. Our data collecting methods have yielded distributions that are a direct reflection of the actual times spent on each step or are an estimation of the time spent by the individual actually performing the function. The simulation results very closely approximate the quantity of components actually inducted and repaired during the fourth quarter of fiscal year 1997. Numerous simulations with suggested modifications to the repair process will be run in an effort to uncover TAT and WIP reductions. The results of these simulations will be discussed in the next chapter.

VIII. M&S DATA PRESENTATION & ANALYSIS

A. OVERVIEW

The state of Naval aviation readiness is directly linked to the availability of material for timely, cost efficient repair of aircraft in inventory. In turn, the ability to manage repair TAT significantly influences system inventory investment levels and supply system responsiveness to fleet needs. The future holds much budgetary uncertainty and analysis of repair TAT is essential to ensuring efficient repairs of critical aircraft components. In preparation for analysis of the repair process we reviewed both public and commercial sector repair and business practices to contrast each for potential improvements. United Airlines has recently recognized the crucial relationship between repair TAT and inventory investment levels and instituted process changes aimed at reducing TAT. It is important for DoD to continue looking for similar efficiency gains and capitalize on the potential they present.

Striving to conduct research impacting readiness we identified a component designated as a "system readiness degrader", for repair process modeling. We then examined and documented the logic and thought processes involved in identifying and defining each step in building the model and their associated distribution times. Having constructed the model, assigned distributions, and validated its potential as an analysis tool, we now must identify and apply potential enhancements to the repair process that may yield

TAT and WIP reductions. Simulations run with several BYFA model enhancements will be analyzed to identify their potential effect on TAT and WIP levels.

Our purpose for experimenting with enhancements to the items repair process is to improve readiness and produce monetary savings through improved cycle time and reduced inventory investment. By applying M&S techniques we can analyze the outcomes of multiple experiments without physically altering the actual repair process. This saves time and money, allowing exploration of innovative alternatives.

Several functions inherent to the repair process standout as potential areas for focusing improvement efforts. This chapter will examine four specific functional area enhancements and discuss the potential incremental TAT or WIP savings which each could yield. The four areas of concentration are:

- **(Enhancement One)** Conducting the Sale Processing function in building 472 vice building 378, thereby eliminating the required movement of the component back to the responsible shop prior to Custody Exchange.

- **(Enhancement Two)** Enhancing initial availability of material required for repair from the current 20% to 50%, thereby reducing the item's time in the delay awaiting material status.

- **(Enhancement Three)** Moving QA inspections into building 472 to eliminate the current waiting period for QA inspections in building 378.

- **(Enhancement Four)** Altering DDDC pull and stage personnel schedules to coincide with NADEP to facilitate more rapid turnover of material.

These four model modifications were made individually and simulations were run independently for each scenario to analyze for potential savings. Finally, replications were run on the model with all four enhancements made simultaneously in an effort to examine the aggregate potential change. This aggregate enhancement will be referred to as

Enhancement Five. Each simulation run has average TAT, WIP, induction level, and sales data associated with it. Each one will be subsequently discussed and compared to the baseline model in order to identify potential savings each modification could yield. Statistical outputs were collected from the respective simulations and used in Tables 8.1 through 8.5 to document the potential average TAT and WIP reductions which could be expected if the applicable changes are made to the repair process. Figure 8.1 is a visual depiction of the base model and can be used to understand the logical flow of the repair process.

B. ENHANCEMENT ONE *(SALE PROCESSING)*

Sale processing documents the completion of the repair process and administratively credits the responsible shop with completion of repair. Current NADEP business practice calls for sale processing to be conducted at the responsible shop. As illustrated in Appendix D, following completion of repairs, QA, and routing for painting, the item travels back through the transportation network to the responsible shop for sale processing. Figure 8.2 depicts the model following Enhancement One changes. Table 8.1 provides data for comparison of the baseline repair process with Enhancement One.

	Baseline Avg	Enhancement Avg	Percent Change	Potential Savings
TAT	23.467	22.047	6.05%	
WIP	22.557	20.342	9.82%	**$13,882**
Inductions	95	91		
Sales	65.9	64.233		

Table 8.1. Enhancement One Data

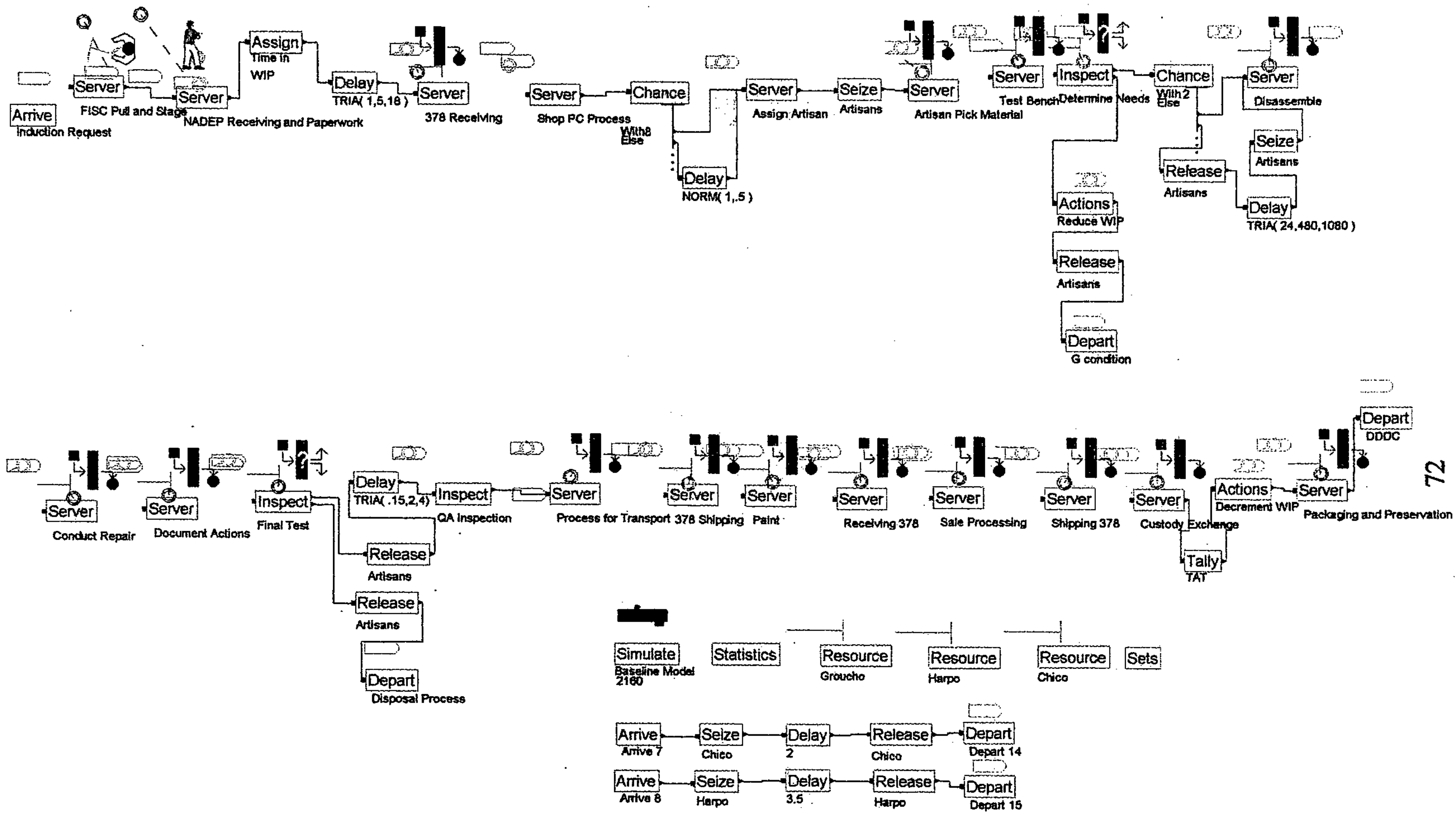


Figure 8.1. BYFA Base Model

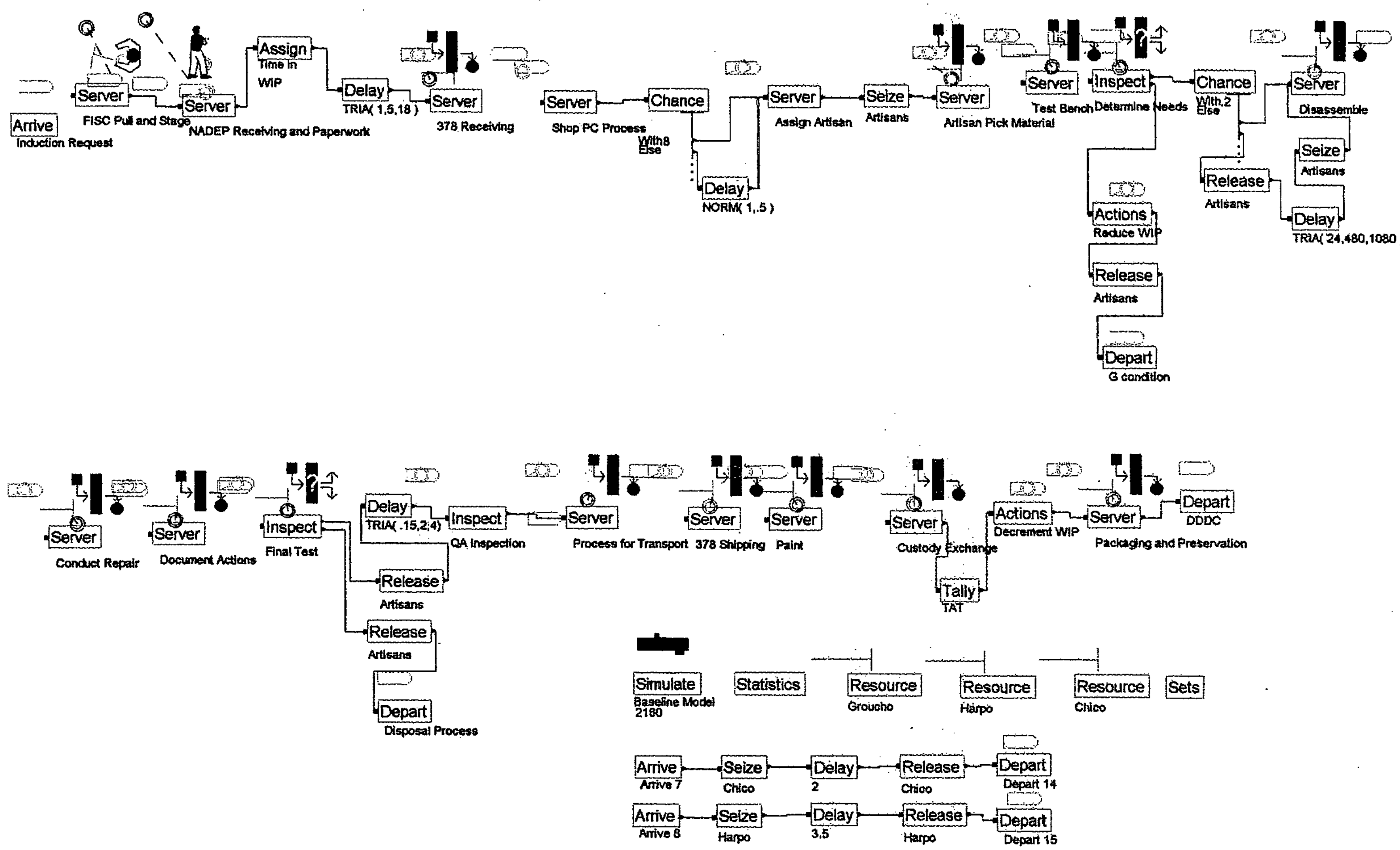


Figure 8.2. BYFA Enhancement One

In reviewing the process, it became readily apparent that the vast majority of the time required to conduct sale processing is the transit time back to the responsible shop, handling at the shops dispatch center, and repetition of these steps following actual sale processing. Examining the data in Table 8.1, a comparison of TAT's suggest that handling the items in the current fashion adds approximately 1.4 days to the TAT for an item. If sale processing and credit to the responsible shop could be conducted immediately following painting and the item routed directly to building 36 for custody exchange, approximately 1.4 days could be eliminated in the repair pipeline time. This reduction of TAT in the repair process directly translates into fewer items in WIP inventory. A corresponding reduction in average WIP inventory of 2.2 items can be realized. At a cost of $6,310 per item, Table 8.1 shows the potential **savings of $13,822** could result from this process enhancement. Appendix G graphically illustrates the reduction in WIP inventory investment possible in implementing Enhancement One. Further comparisons of the data in Table 8.1 support the conclusion of pipeline inventory savings by showing a reduced induction rate necessary to achieve comparable sales levels.

C. ENHANCEMENT TWO *(MATERIAL AVAILABILITY)*

Table 8.2 data will be used in analysis of Enhancement Two recommendations and Appendix H provides a graphical comparison of each alternative. No visual image of Enhancement Two is provided as it is merely a modification of material availability.

	Baseline Avg	Enhancement Avg	Percent Change	Potential Savings
TAT	23.467	15.817	32.6%	
WIP	22.557	14.675	34.9%	**$49,725**
Inductions	95	85	10.5%	
Sales	65.9	65.7	Negligible	

Table 8.2. Enhancement Two Data

The material requirements process requires an artisan to requisition his needed material and if not available, place the item into a delay status until all the piece-parts are available to complete repair. Per shop 36 foreman, material is available on demand for BYFA, meaning available in local stock, an average of only 20% of the time. For the remaining 80%, there is currently an average waiting period of 20 days for receipt of all material requirements. The maximum waiting period for material is 45 days. If the equipment specialist determines awaiting parts time will exceed 45 days, the component will be transferred from "M" to "G" condition, be removed from WIP inventory, and TAT ceases. While this is unusual, occurring for roughly 1% of the total items processed, it still occurs periodically. Repair delays of this nature amount to additional time required for completion of the repair or longer TAT's. While TAT stops when a component is in "G" condition, when it is re-inducted into the repair process, following receipt of piece part requirements, it must repeat all its previous steps. Time in "G" condition does not count against NADEP TAT but none the less ties inventory up in a non-usable fashion.

Processing delays due to material non-availability are an obvious contributor to TAT and have a direct relationship to WIP and pipeline inventory investment levels. The bottom line is the longer it takes to repair a component, the greater the investment in pipeline inventory. The cost of piece parts necessary for repair of a BYFA component are negligible compared to the procurement cost of the item. The question then is where is it most cost efficient to invest in inventory, the component level at $6,310 per unit or retail level at a fraction of the cost? WIP inventory buildups, due to lack of availability of piece parts, are effectively wasted inventory. An item sitting in WIP awaiting piece-parts does nothing to benefit the end user, the aviation squadron. It simply is waste. Efficient pipeline inventory investments are those which have high turnover and service rates. Retail stock levels of piece parts must be managed to ensure greater availability to the repairing activities. Buildup of inventories at this level above projected needs is clearly not the answer, but implementation of more accurate forecasting methods is a must. All NADEP's are implementing Material Requirements Planning II (MRP II) as a planning and forecasting tool for repair processes and this should aid in better forecast retail material requirements.

Enhancement Two simulations indicate an improvement in material availability from 20% to 50% could yield reductions in TAT of 7.65 days. The simulations we have run only address improving the immediate availability of material from 20% to 50%. Repair delay times associated with waiting for the remaining percentage of retail material needs could also be addressed for potential impacts. Once again reductions in TAT translate into WIP savings and reduced quarterly induction requirements while maintaining comparable sales levels. Average WIP level would drop by 7.9 units and induction requirements would drop by 10 units. The resulting **potential savings of $49,725** associated with increased material availability would have to be weighed against the increased cost of procuring and handling piece parts inventory and variability of demand. But, as we learned at United Airlines and we intuitively know, the cost of piece parts support is likely a fraction of the potential savings from reduced component pipeline inventory investments. A WIP inventory reduction of 7.9 units yields very significant inventory savings, surely greater than the cost of stocking the piece parts to the 50% service level.

D. ENHANCEMENT THREE *(QUALITY ASSURANCE (QA))*

The data in table 8.3 represents the results of Enhancement Three, moving QA inspections to building 472. Figure 8.3 provides a visual image of the model following Enhancement Three.

	Baseline Avg	Enhancement Avg	Percent Change	Potential Savings
TAT	23.467	23.481	Negligible	
WIP	22.557	22.081	2.1%	**$3,150**
Inductions	95	93		
Sales	65.9	64.933		

Table 8.3. Enhancement Three Data

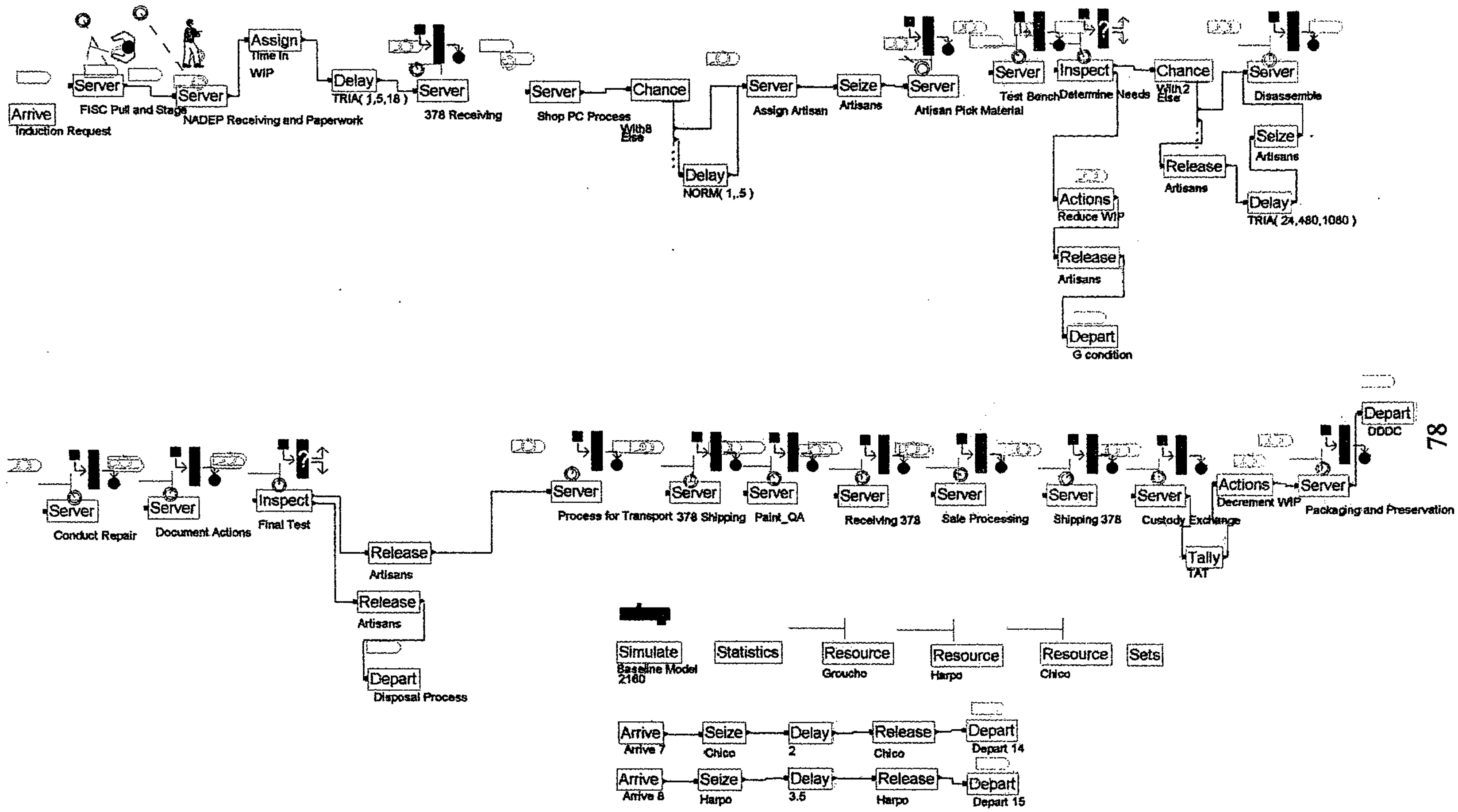


Figure 8.3. BYFA Enhancement Three

QA inspections are conducted randomly at the end of the repair process. Inspectors roam from shop to shop conducting inspections. The randomness associated with the inspector's schedule and completion of repairs causes items to wait in a queue for the inspectors arrival. The model's waiting period for the function has a triangular distribution with minimum, mode, and maximum times of 9 minutes, 2 hours, and 4 hours, respectively. As every repaired component must be available for QA inspection, they must all wait for the inspector's arrival. Locating a QA inspector at the paint shop dispatch center and conducting all QA inspections there could reduce the randomness of QA inspections, allowing items to flow straight from the repair to paint shop without the queue time. Failure rates at QA inspections are negligible, effectively never occurring, so the requirement for returns to the responsible shop for reprocessing would be on an exception basis.

While the waiting time associated with QA inspections is minimal, incremental gains, even minor ones, can yield pipeline inventory savings. In Table 8.3 simulations indicate this change would yield no significant TAT reductions but a reduction in WIP inventory levels of .5 items may be realized. Appendix I provides graphical evidence of the minor effect this enhancement would have on the repair process. However, when coupled with other incremental gains, this enhancement does contribute to TAT and WIP reductions and should be considered.

E. ENHANCEMENT FOUR *(DDDC SCHEDULE CHANGE)*

The fourth focus of analysis is the exchange of material from DDDC to NADEP. No visual image of Enhancement Four is provided as it is merely a schedule change for the DDDC pull and stage personnel. Refer to Figure 8.1 for an image of the process. Table 8.4 provides the data resulting from the simulation.

	Baseline Avg	Enhancement Avg	Percent Change	Potential Savings
TAT	23.467	23.603	Negligible	
WIP	22.557	22.584	Negligible	**Negligible**
Inductions	95	95		
Sales	65.9	65.7		

Table 8.4. Enhancement Four Data

As indicated in Chapter IV, following the induction request, DDDC pulls the "F" condition asset and stages it for transfer to NADEP to initiate the repair process. NADEP TAT does not commence until the custody transfer is completed but the time associated with DDDC pull and stage still counts in the calculation of total TAT from a fleet readiness perspective. Under the current process DDDC personnel work 11am to 7:30pm pulling material. Material is queued until the next morning at 7am when NADEP personnel arrive to accept custody. If DDDC personnel were to work the same shift as NADEP personnel, or work an earlier shift such that pulls and custody transfer could be conducted in the same day, potential incremental gains may be realized in aggregate TAT and reductions in pipeline inventory investments might be discovered. Table 8.4 data indicates this change would not have any significant effect on TAT of WIP levels. When graphed, depicted on

Appendix J, it is clear that the modeled change would not be worth implementing as there would be no derived benefits. Many process modification which at first seem to suggest they could contribute to TAT or WIP savings can be analyzed for effectiveness using M&S.

F. ENHANCEMENT FIVE *(AGGREGATE EFFECT)*

Appendix K graphically illustrates the aggregate effect of conducting all four changes simultaneously. Refer to Figure 8.1 for an image of the process. When presented in a tabular form as Table 8.5, the following aggregate savings are possible:

	Baseline Avg	Enhancement Avg	Percent Change	Potential Savings
TAT	23.467	15.299	34.8%	
WIP	22.557	14.169	37.2%	**$52,928**
Inductions	95	84	11.5%	
Sales	65.9	66.3		

Table 8.5. Enhancement Aggregate Data

These savings hinge on the commitment of the time, efforts, and resources of a number of activities, not just NADEP. A coordinated effort would be required for the application of these principles to the complete range of items that the NADEP repairs.

Appendices L and M show graphically the results of calculating a 95% confidence intervals for the average TAT and WIP levels for the baseline model and each subsequent enhancement. What these graphs signify is that the probability is 95% that, under the model's assumptions, the mean TAT and WIP can be expected to fall within the intervals. It is important to know the range TAT and WIP levels could have.

While we only examined four enhancements to the baseline model, many more possibilities for analysis exist. Modeling of the repair process is a very useful tool for testing the effect process enhancements could have on repair TAT and WIP inventory levels. The intent of this research has been to impact readiness and inventory investment through repair cycle time reduction using M&S as a logistics analysis tool. The final chapter will present conclusions and provide recommendations for further research in repair cycle time and pipeline inventory reduction.

IX. CONCLUSIONS AND RECOMMENDATIONS

A. BACKGROUND

Chapter VIII detailed the potential savings yielded using M&S as a logistics management tool in pursuit of cycle time reduction. The use of M&S techniques, while common in many engineering disciplines, is new to logistics management. As evidenced by the data presented in the previous chapters, it can be a powerful tool with great potential. Logistics management plays an increasingly vital role in reducing the expenditure of resources on non-value added activities. In order to remain competitive in today's public and commercial sectors each activity in a products life cycle must contribute or add value to the product.

This research has focused on the processes involved in the repair of a single item at NADEP North Island. M&S analysis has aided in the identification of potential process changes that could yield significant savings in pipeline inventory investments. As discussed in chapter II, reduction in repair TAT's is key in reducing the Navy's dependence on expensive inventory investment and freeing funds for operational requirements. Inventory investment levels is everyone's responsibility, NADEP coordination with NAVICP and NAVAIR, coupled with the use of M&S to identify potential process changes, could lead to TAT improvements and significant inventory investment reductions. The scope of this research has been limited but it has demonstrated that M&S can uncover potential efficiencies and savings through process modification. M&S enhances our ability to modify these processes by eliminating the impact of testing on an actual system and costs of trial and error implementations by evaluating the feasibility and value of those changes.

Improved fleet aviation readiness should be the ultimate goal of all material handling activities. Whether storing, transporting, issuing, or repairing components, each step in the component life cycle should strive to enhance readiness. Any incremental savings realized through reducing necessary pipeline inventory levels can be applied to modernize existing fleet capabilities. Focusing on reducing the time associated with each step between component failure in the fleet and its return to fleet availability in an RFI condition is essential to improving readiness. Repair TAT is but one of many issues that can be explored for greater efficiencies in the component flow processes. Each activity which handles repairable components stands to gain from the use of M&S analysis techniques in their effort to contribute not detract from fleet readiness.

In the current austere defense budgetary climate, investment in tools that can aid in yielding significant savings is critical. Inventory management practices relying on large component inventory levels to mask poor business or repair practices cannot be allowed to continue. It is the responsibility of every DoD employee whether active duty or civil service to examine current practices and search for efficiencies. Cultural biases and parochial views slow the much needed progress in materials management.

Repair of components is a job shop activity. Job shop's inherently possess greater input and process variability. This variability creates a challenging environment for controlling capital investments in resources. Both the commercial and military sectors face the same obstacles in stemming the growth of reliance on inventory. The commercial sector has only recently recognized the relationship between repair TAT and readiness and taken steps to address it. As we detailed in Chapter V, United Airlines, who's component repair business is very much like DoD's, has used TAT reduction to drive down inventory investment. While the commercial sector has secondary markets making it easier to liquidate idle inventories, DoD can learn from their business and repair philosophies. We must search for and exploit every tool we can to help drive repair TAT down so we can reduce investment in repairable inventories. So, while a job shop environment presents some unique challenges, they are not unique to DoD. Many policies and lessons from commercial industry should be explored for potential benefits to DoD materials management.

The hardware and software tools used in this research are commercial off-the-shelf and can be acquired for under $12,000. The software package, ARENA, is designed to run in a Microsoft Windows 95® environment and is easy to learn and use for anyone with a working knowledge in a Windows 95® environment. Any standard IBM compatible computer with 16 megabytes of Random Access Memory greater will run the program. Obviously, the greater the processing speed the quicker simulations will run. While most processes can be modeled and simulations run with relatively minor investments in physical resources, time and training of personnel are essential for the effective use of M&S as a logistics analysis tool. NADEP North Island Component Repair Program has the necessary hardware to run the program. They would require purchasing of the software and training of personnel in the use of the package. A dedicated management philosophical approach to use of M&S for process improvement is required for the effort to yield productive positive results. M&S is not in itself a fix for process improvement woes, it is merely a tool to use and must be supported with adequate training of personnel in its use as a management analysis tool.

Many opportunities exist to use M&S in logistics. Our examination of component repair processes has just scratched the analysis surface. We have focused our efforts on the process steps from component induction to sale in an RFI condition. Many other activities handle repairable components as they weave their way from the user through the repair pipeline and back to the customer. Each of these process steps potentially benefits from the application and thorough analysis M&S techniques can provide.

B. CONCLUSIONS AND RECOMMENDATIONS

- **Conclusion 1** - Modeling and Simulation as an analysis tool can greatly aid in the effort to streamline logistics processes.
  - **Recommendation**: Military activities involved in all phases of material management should explore the use of M&S. The depot repair environment particularly lends its self to gains M&S can provide. While the use of M&S in the depot repair environment can greatly enhance productivity, it should be viewed as merely a tool to assist in the improvement effort. Training personnel in its use and management of the repair process are the key elements of progress.

- **Conclusion 2** - Repair TAT reductions at the NADEP are a vital element of remaining competitive and sustaining fleet readiness.
  - **Recommendation**: Educate workforce on the relationship between repair TAT and WIP levels. Focus improvement efforts on TAT reductions.
- **Conclusion 3** – Lack of material availability is the key element driving current repair TAT.
  - **Recommendation**: Coordination between DLA, NAVICP, NAVAIR, and NADEP in setting and sustaining piece-parts inventory levels to meet repair needs is critical in reducing repair cycle times.
- **Conclusion 4** - Like commercial sector businesses can provide valuable examples of how logistics and inventory issues may be addressed.
  - **Recommendation**: Search commercial sector for like business activities and compare and contrast practices in an effort to enhance military material management effectiveness.
- **Conclusion 5** – Utilization of Naval Post-Graduate School (NPS) research capabilities for logistics related research can pay dividends and provided valuable input to activities which may not have internal resources necessary to examine processes effectively.
  - **Recommendation**: Military activities not accustomed to exploring internal processes should contact NPS with a shopping list of problems/issue they wish to explore.

APPENDIX A. MASTER DATA RECORD

```
                                        M A S T E R   D A T A   R E C O R D        PRINTED ON: 11/14/96  BY:
      CONTROL   GROUP
LOC  MDRCC   ----CIN-----            NOMENCLATURE                  QUANTITY  RDI  ORIGINAL-DATE  SRC  REVISION DATE QA-CD MS-CD
101  85XPA   0000P4030000      GENERATOR  AC BRUSHLESS                01      01     09/30/96      Z      11/09/96     AH7   000
     CAP   DMDS EE DISP DAYS            SC SCC MTR DAR PLND  P&E   B     WORK    CONF ENG MODEL  SYSTEMS QA VERIF INST  CUST
    CODE WAC IND IND CD  AVL  ROT  OOS  CD  CD  CD IND CODE CODE  CODE  UNIT-CD CODE MOD CODE    CODE  REF-CD   CMP   PRG CD
102   7   3   N   N  BW  035                A       G     G    A                      A-6                               LS
      INDUCTED FEDERAL STOCK NUMBER         MODIFIED FEDERAL STOCK NUMBER INST-COMP-IIC    SM&R CODE
103        7RE  6115 011351541 FA                7RE  6115 010462415 FA
                                                                                               WKLD ACC
    PROD-STD CLASS PROC-COST  EXEC-STD-HRS MOD-STD-HRS    PLN-STD-HRS    BDG-STD-HRS    DRP  WK-AREA FACTOR  SKD-LMT CAP-DATE   POF
104    18.90   A     0000161       21.00          0.00          21.00          21.00       7       A              999            095

      LN        MANUFACTURER  PART NUMBER          MFR CODE   PMA   LN        PUBLICATION NUMBER         PUB TYPE
105   01        2CM352D2C                          30221       P    01        03-50CDD-1                   PUB



                         TRADE AREA                               COST  MDR
  DML  ZONE  DLM TASK       IND  A/C    A/C-WORK-PHASE           CENTER LOC  ASKARS-KIT   HT   SZ  FRZ   HARDWARE-KIT     ASKARS-CHAIN
106                                                                93
         PRESERVATION-CODE       PACKAGING-CODE                      EQUIP-SERIAL-NO  BLD-NO     CUSTODY-SHOP

    MDRCC      DISASY-CIN         MDRCC       RTG-CIN           MDRCC        ASY-CIN


        TECHNICAL DIRECTIVES       LOC     TECHNICAL DIRECTIVES       LOC      TECHNICAL DIRECTIVES       LOC     TECHNICAL DIRECTIVES
   ORG TITLE NUMBER                   ORG TITLE NUMBER                   ORG TITLE NUMBER                    ORG TITLE NUMBER
501   NA    03-50CDD-1



                                        M I S C E L L A N E O U S'   I N F O R M A T I O N   G R O U P
   TYPE                                           SPECIAL INSTRUCTIONS
601   4                                    SCHEDULE REMOVAL CARDS REQUIRED
602   4                                    NEW P/N 362530-1-1
```

APPENDIX B. SHOP ORDER

SHOP ORDER - UADPS FOR NAS
NAVAVNDEPOT NI. 4710/81 (REV.11-89)

PROGRAM 3 (COMPONENTS)
JN 340PU99 OA AH6 MS 600 U0405912 MATL PRICE 2033.00

LINK NO.	PART NAME	RELATED DESCRIPTION	MOR CONTROL CODE	COMPONENT IDENTITY NO.	PAGE
U040591	PRI 2 MOTOR, ALT	WK NO 50 NWRN327249 7458 NI	3BYFA	0000PU990000	1 OTR 4

PRODUCT STD.	CL	DISP. CODE	TMS NAME	SEQUENCE	INDUCTED NATIONAL STOCK NUMBER	MODIFIED NATIONAL STOCK NUMBER	QUANTITY
	A	BW	507458	0001	7REF6105-011237973-CS		1

PROCUREMENT COST	MODEL CODE	MANUFACTURER'S PART NUMBER	PUBLICATION NUMBER	SPARES	BU.NO.
5170	S-3	516544-5-1	03-5CHA-73		099999

LINE NO.	SHOP NO.	GEO AREA	SHOP CAT. CODE	START DAY	COMP DAY	MHC	OPERATION CODE	STD CD	OPERATION STANDARD	OPERATION DESCRIPTION	CERTIFIER / VERIFIER	DATE
	93001	A	DX	227	227					NO QCL		
03	93001	A	BP	228	232	4	CIRR	D	.39	INDCTN/RTRN/RCNCLTN	JC23	SEP 8 19
	93806	2M	CX	234	234					EVALUATE	C3202	9-17-92
05	93806	2M	44	234	234	4	UBUC	D	.50	6737 TEST,POWER-ACT TST STND		
	93905	M	CX	238	238					WAITING PARTS		
	93806	2M	CX	238	238					0150 DISASSEMBLE		
08	93806	2M	XR	238	240	4	UBUA	D	11.98	0180 REPAIR		
	93806	M	70				DMDS			0999 CIRCLE MAL/ACTION CODES M		
10	93806	2M	44	240	240	4	UBUB	D	1.50	0230 FINAL TEST		
11	97404	4F	44	241	243	4	ZZMA	D	.12	8533 3IU GRAY		
	93806	2M	CX	001	001					0340 SELL		
			EX						QV-FINAL-ACCEPT			
			EX						BLDG 36	RCNCLTN		
15	93001	A	XF	002	004							
						~~***** DMDS TRANSACTION REQUIRED *****~~						

LINK NO.	PART NAME	UNIFORM DATA CLASSIFICATION CODE STRUCTURE	COMPONENT IDENTITY NO.	PAGE
U040591	MOTOR, ALT	340PU99-3 U0405912	0000PU990000	1-1

LINK NO: U040591 F/E DOCUMENT NO: NWRN3272497458 SEQ NO: 0001

MOD NSN:

PART NAME: MOTOR, ALT PART NO: 516544-5-1

FOR LABOR TRANSACTIONS ONLY

LINK NO: U040591

APPENDIX C. SYSTEM INVENTORY PRIORITY (SIP) REPORT

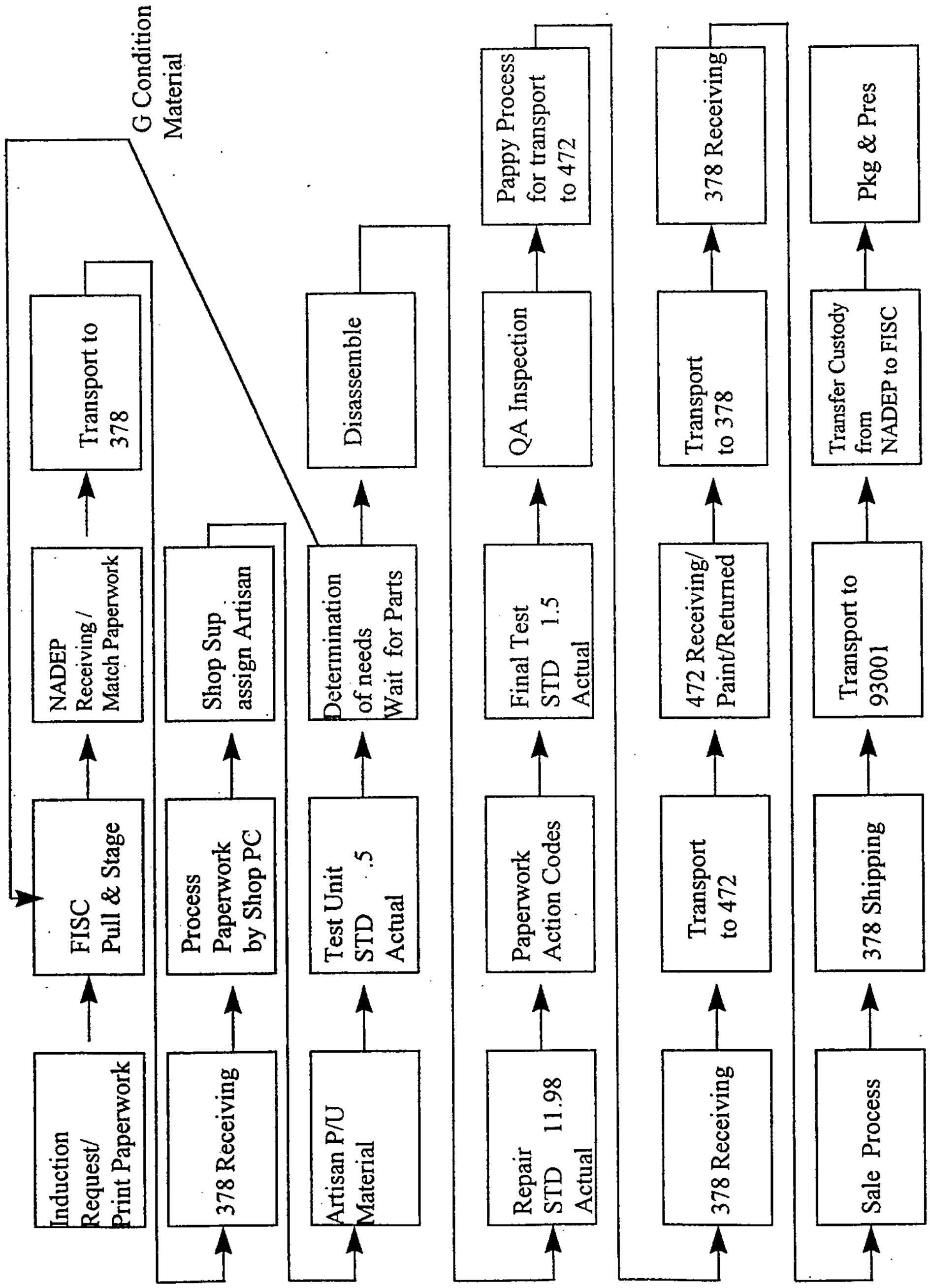
UNITED

JOB 2525-1 SIP PRIORITY AND GAIN REPORT PAGE 29
08/26/97 ECSS SEQUENCE

WORK CNTR 126F WK DAY FCTR 1.8

PCN/X-REF	PART-NOUN	DSP CDE	Q REQ TODAY	SERV STAT	MSA	---TOTAL ACTUAL RCS UNITS:--- PS	Q INPROC	HOS	INTRN	VEN	QCJ	ELS QTY	BNCH TIME	DAILY PNR	ECSS	GOAL ECSS
S641;9915	MR27283 VLV TRA	A	3	-2	35	2	1			22		1	3.7	.738	2973	1459
643;9091	MR27314 UNIT	A	5	-5	7	2	4					1	17.2	.198	907	339
S130;9123	MR27505 VALVE A	A	3	-3	6	1		1				1	6.0	.034	509	135
S641;9868	MR27838 ACT LE	A	5	-5	9	7		3				2	16.7	.078	415	53
643;9209	MR22172 SERVO	A	1	-1	5	1						1	1.5	.069	383	153
643;9006	MR27250 CONTR	A	3	-3	3			4				1	15.3	.011	338	13
611;9047	MR27639 MOTOR		1								4	1	6.5	.074	329	115
641;9175	MR27892 ACTUAT	A	4	-4	5	5		1				1	9.0	.064	312	29
S180;9262	MR27501 MODULAR	A	1	-1	2	3						2	8.0	.023	300	73
641;9614	MR27911 PWR UN	A	5	-5	6	2	3		2		1	1	24.1	.046	285	21
641;9275	MR27937 UNIT	A	2	-2	3	4						1	36.2	.022	283	94
643;9090	MR27120 UNIT	A	2	-2	4	2	1	1				1	13.7	.070	277	104
S643;9000	MR27393 CONTR	A	1	-1	3	3						1	20.1	.039	247	124
S641;0073	MR27630 ACT WG	A	3	-3	8	3	4				2	1	15.4	.104	183	96
641;9188	MR27367 ACTUAT	A	1									1	20.0	.005	180	32
S641;4117	MR27680 VA HYD	A	2	-2	5	3						1	2.9	.011	169	4
643;9009	MR27440 CONTR	A	1	-1	3	2						1	19.1	.058	166	180
641;9616	MR27263 VLV RUD	A	4	-4	8	1		5				2	13.6	.060	160	21
S641;9913	MR27436 CONTROL	A	4	-3	4	1	1			1		1	50.9	.045	160	52
641;9162	MR27909 COMPUT	A	2	-2	4	2					1	1	12.7	.024	147	11
641;9186	MR27269 CYLIN	A	1	-1	1			1				1	1.5	.004	146	30
643;9005	MR27109 CONTR	A	1	-1	4	2						1	34.4	.028	128	83
180;9213	MR27412 MOD-STA	A	1	-1	3	2			1			1	9.3	.014	119	56
S641;9601	MR27695 ACT FLT	A	1	-1	5	5	1	1				2	16.2	.075	119	25
180;9147	MR27202 CONTRO		1									1	40.0	.003	114	5
642;9002	MR27439 VALVE		1									1	8.8	.001	110	
S641;2622	MR27152 VALVE		1									1	1.5	.001	107	
643;9003	MR27621 VALVE	A	1									1	4.3	.001	107	
S641;9914	MR27356 SW PRES	A	1	-1	2	3						2	3.9	.011	91	11
641;9169	MR27890 ACTUAT	A	1	-1	5							1	9.0	.043	84	13
641;9664	MR27897 ACT-LE	A	1	-1	10	1		3				4	11.7	.079	84	42
S641;9926	MR27284 CONTROL	A	1	-1	4	3	3				1	1	36.3	.021	80	13
S641;9606	MR27262 CYL-RUD	A	1	-1	9	5						1	17.3	.042	75	40
S643;9094	MR27587 VALVE	A	1	-1	6	1						1	10.5	.015	72	34
641;9878	MR27354 COMPUTE	A	2	-2	3	2	3					1	16.7	.016	70	5
S180;9421	MR27620 ACTUAT	A	1	-1	2	2						1	10.7	.001	62	
641;9087	MR27352 SWITCH	A	1	-1	2			3				1	11.2	.004	62	
S641;8711	MR27593 VA HYD	A	1	-1	3							2	13.7	.006	58	11
S641;9661	MR27896 ACT-LES	A	1	-1	4	2						1	21.9	.021	57	6
S641;9662	MR27634 ACT-GRN	A	1	-1	6	1		1				1	8.9	.031	56	20
644;0078	MR27648 SERVOV	A	1	-1	3							1	1.5	.001	54	
641;9660	MR27895 ACT LE	A	1	-1	6	3		2				1	18.8	.055	53	67
643;9205	MR27531 MODUL	A	1	-1	4	2						1	26.8	.005	51	6
181;1458	4549-600U PRIOR	A	1	-1	2	2						3	2.8	.005	41	16
S643;0547	MR27444 VLV AY-	A	1	-1	5		2					1	2.5	.005	26	10

APPENDIX D. BYFA REPAIR FLOW DIAGRAM



APPENDIX E. MODEL DISTRIBUTIONS

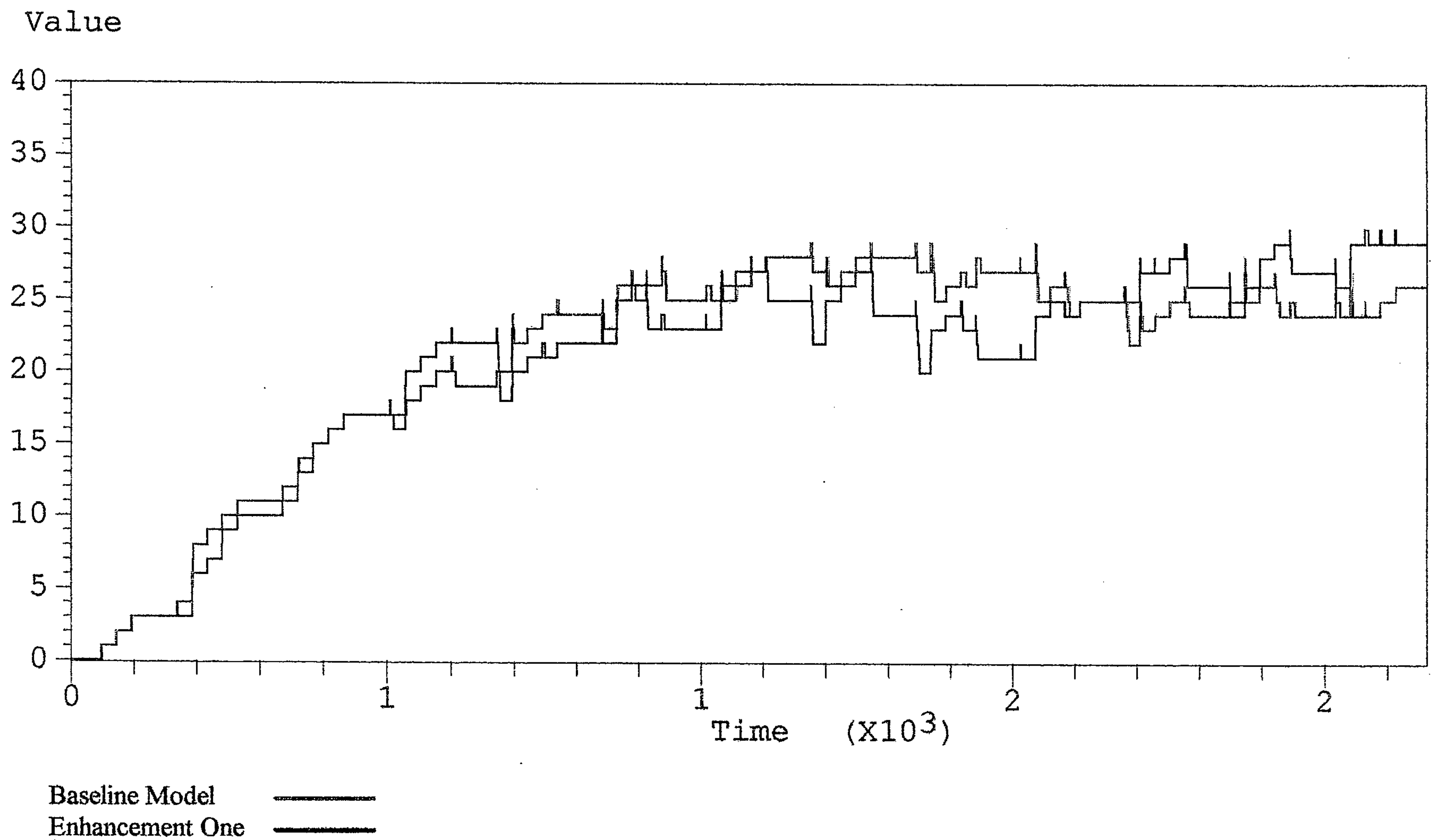
	Step	Distribution
Phase 1	Induction Request	Specified Rate
	DDDC Pull & Stage	N(.6, .12)
	NADEP Receiving & Paperwork	N(.5, .1)
	Route Time	TRIA(1,5,18)
Phase 2	Building 378 Receiving	N(1.5, .33)
	Routing to Shop	UNIF(1,2)
	Shop PC Processing	UNIF(.1,.2)
	Delay to assign Artisan (Chance .2)	N(1,.5)
	Assign Artisan	N(.1, .05)
	Artisan Pick-up Material	UNIF(1,1.2)
	Test Bench	N(.23, .23)
	Material Inspection	N(2,1)
	Probability of Failure	.01
	Delay (Material Receipt)	TRIA(24,480,1080)
	Disassemble	N(1, .25)
	Conduct Repair	N(11.02, 3.31)
	Document Repair Action	N(.5, .05)
	Conduct Final Testing	N(.68, .4)
	Probability of Failure	.001
	Delay (Wait for QA Inspector)	TRIA(.15,2,4)
	QA Inspection	N(.05, .05)
	Probability of Failure	.001
	Process for Transport	UNIF(.1,.2)
	Building 378 Shipping	N(1.5, .33)
	Route Time	TRIA(1,5,18)
Phase 3	Painting in Building 472	TRIA(18,24,88)
	Route Time	TRIA(1,5,18)
Phase 4	Building 378 Receiving	N(1.5, .33)
	Sale Processing	N(.1,.2)
	Building 378 Shipping	N(1.5, .33)
	Route Time	TRIA(1,5,18)
Phase 5	Custody Exchange	TRIA(.05,1.25,2.5)
	Packaging & Preservation	TRIA(.5,4,8)
	Route to DDDC Warehouse	N (24,12)
	DDDC, Ready for Issue (RFI)	

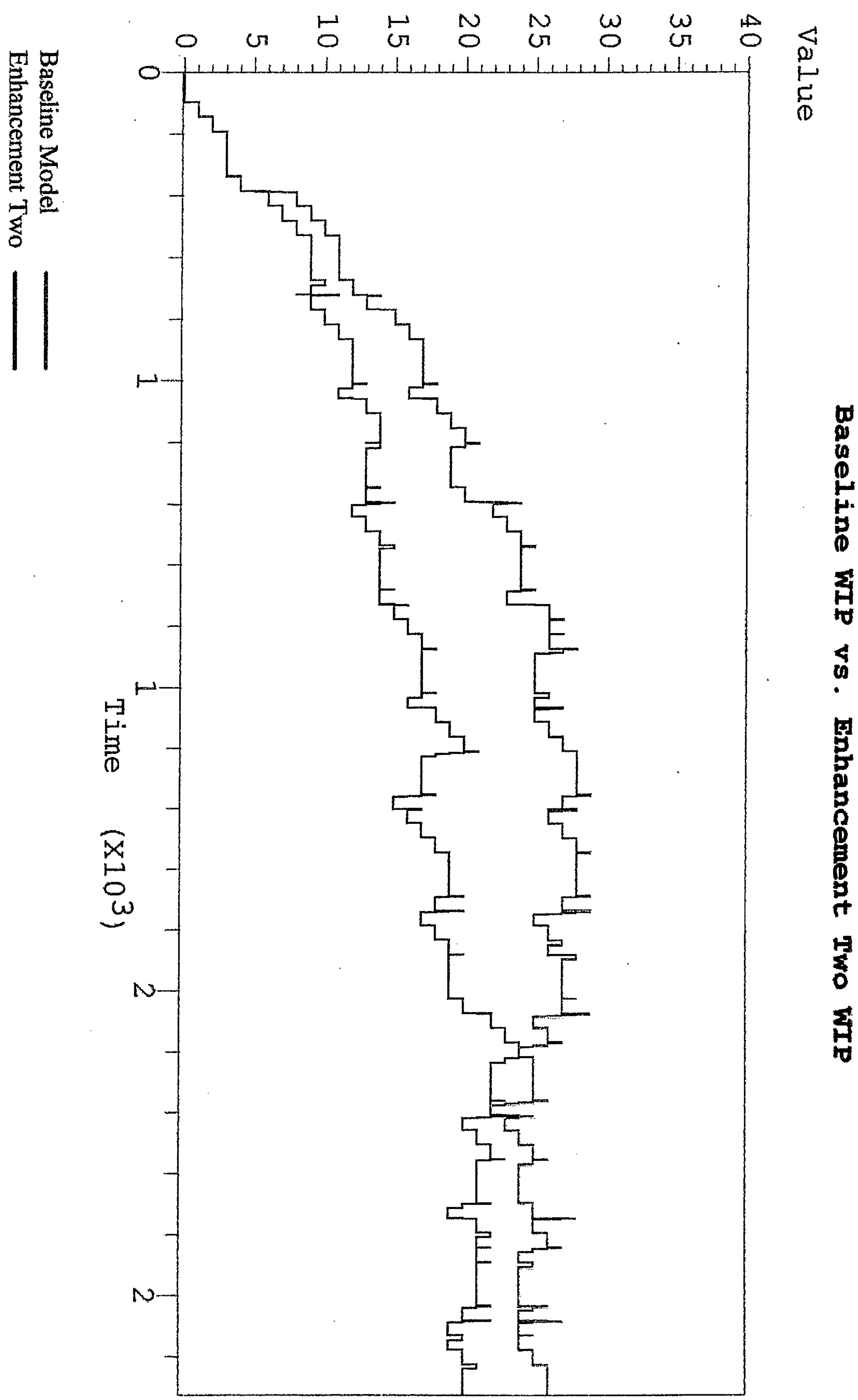
N(X,Y)- Normal Distribution with X hour mean and Y hour standard deviation.
TRIA(A,B,C)- Triangular Distribution with A hour minimum, B hour mode, and C hour maximum.
UNIF(A,B)- Uniform Distribution with A hour minimum and B hour maximum.

APPENDIX F. NADEP NORTH ISLAND: ARTISAN PROCESS TIMES

Line	3	5	8	10	11
	0.11	0.1	12.95	0.3	0.25
	0.81	0.14	12.76	0.43	0.08
	0.53	0.19	11.43	0.3	0.08
	0.1	0.14	13.08	0.42	0.08
	0.1	0.14	11.38	0.43	0.11
	0.1	0.1	10.23	0.3	0.08
	0.11	0.14	11.33	0.42	0.34
	0.11	0.09	18.67	0.36	0.11
	0.11	0.38	17.12	1.14	0.11
	0.76	0.14	12.16	2.28	0.11
	1.54	0.17	13.44	1.33	0.02
	0.1	0.11	10.78	0.66	0.11
	0.11	0.11	13.06	0.33	0.02
	0.11	0.11	8.52	0.33	0.02
	0.1	0.1	12.18	0.28	0.82
	0.2	0.09	12.42	0.28	0.02
	0.1	0.09	10.22	0.28	0.35
	0.11	0.08	11.77	0.38	0.32
	0.11	0.09	12.22	0.75	0.35
	0.11	0.16	9.55	0.57	0.35
	0.11	0.08	13.72	0.24	0.35
	0.01	0.13	12.82	0.38	0.32
	0.01	0.12	2.9	0.36	0.64
	0.09	0.32	11.39	0.92	0.36
	0.07	0.18	9.86	0.48	0.49
	0.12	0.13	13.11	0.34	0.4
	0.09	0.02	13.32	0.66	0.36
	0.09	0.4	11.79	1.18	0.36
	0.1	0.18	12.55	0.57	0.32
	0.12	0.11	5.42	0.34	0.17
	0.1	0.35	8.75	1.1	0.19
	0.04	1.41.	13.24	0.92	0.36
	0.09	0.17	12.37	0.54	0.36
	0.09	0.09	7.62	0.37	0.32
	0.09	0.13	12.52	0.37	0.32
	0.09	0.13	11.61	0.38	2.54
	0.09	0.13	11.87	0.53	2.52
	0.09	0.18	13.92	0.55	2.54
	0.09	0.37	8.84	1.11	0.29
	0.12	0.3	7.24	0.91	0.86
	0.12	0.37	8.75	1.1	0.47
	0.12	0.34	12.52	1.01	0.19
	0.12	0.37	8.93	1.12	0.28
	0.12	0.13	22.37	0.42	0.48
	0.12	0.09	13.23	0.28	1.37
	0.12	0.09	13.29	0.29	0.57
	0.11	0.3	12.2	0.9	0.57
	0.15	1.32	12.29	0.54	0.57
	0.14	0.2	12.56	0.57	1.1
	0.04	0.4	9.27	1.16	0.53
	0.15	0.14	3.37	0.57	0.55
	0.15	0.32	7.71	0.97	0.53
	0.15	0.35	8.72	1.1	0.53
	0.15	0.33	10	0.99	0.53
	0.15	0.36	8.8	1.11	0.19
	0.15	0.01	12.85	0.05	0.17
	0.15	0.36	8.72	1.1	0.19
	0.14	0.37	8.78	1.1	0.18
	0.15	0.37	8.78	1.1	0.19
		0.27	6.67	1.17	1.6
		0.12	13.37	0.35	0.79
		0.29	12.73	0.86	0.13
		0.06	13.63	0.18	0.12
		0.5	1.98	1.47	0.15
		0.34	10.51	1.01	0.35
		0.2	4.75	0.56	0.24
			11.67		0.29
					0.32
					0.32
Total	9.63	15.6	738.58	44.9	31.3
Avg	0.163220339	0.236363636	11.02358209	0.68030303	0.453623188
SDev	0.228491611	0.232865999	3.312038511	0.404592748	0.532361473

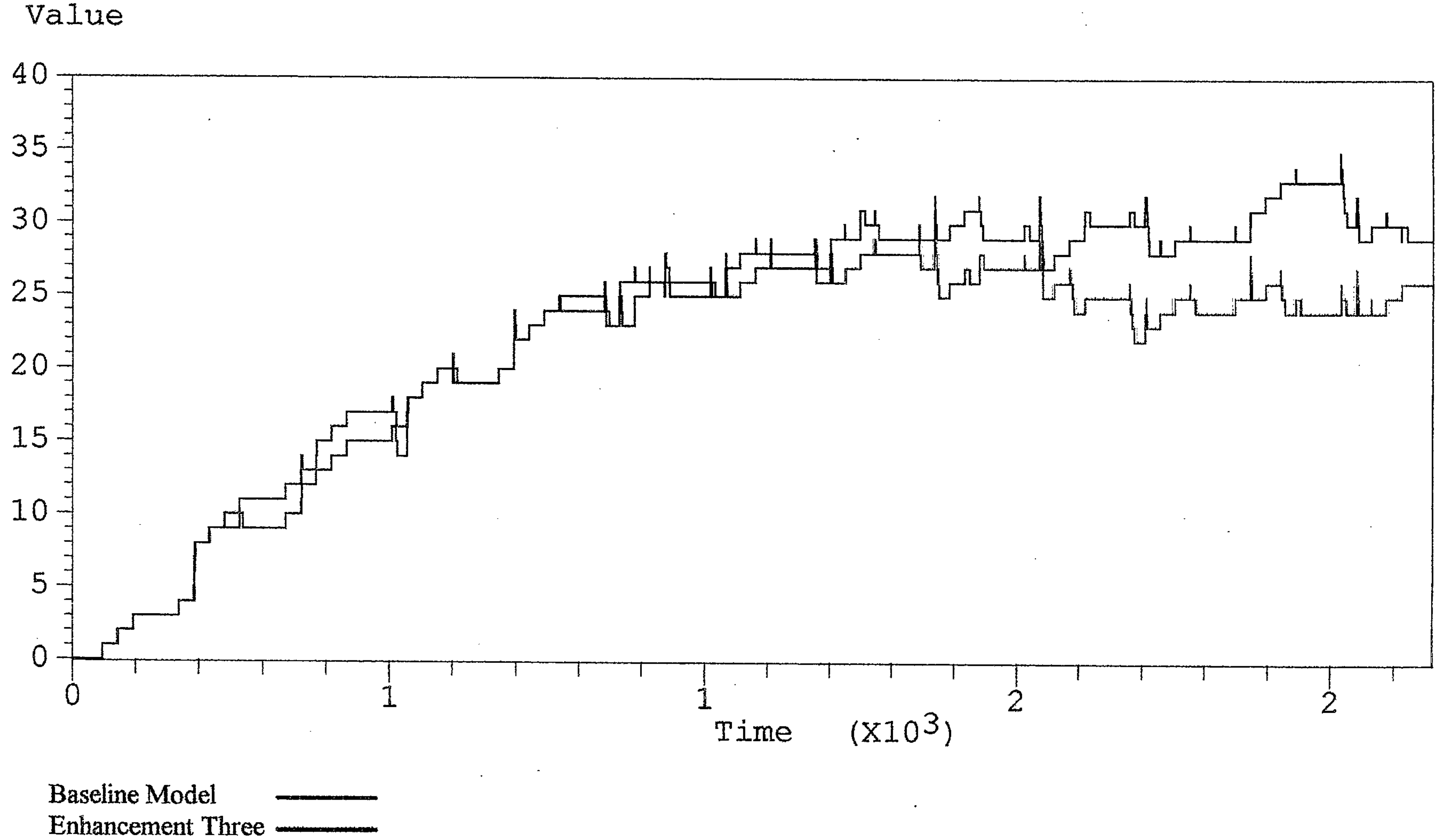
Baseline WIP vs. Enhancement One WIP



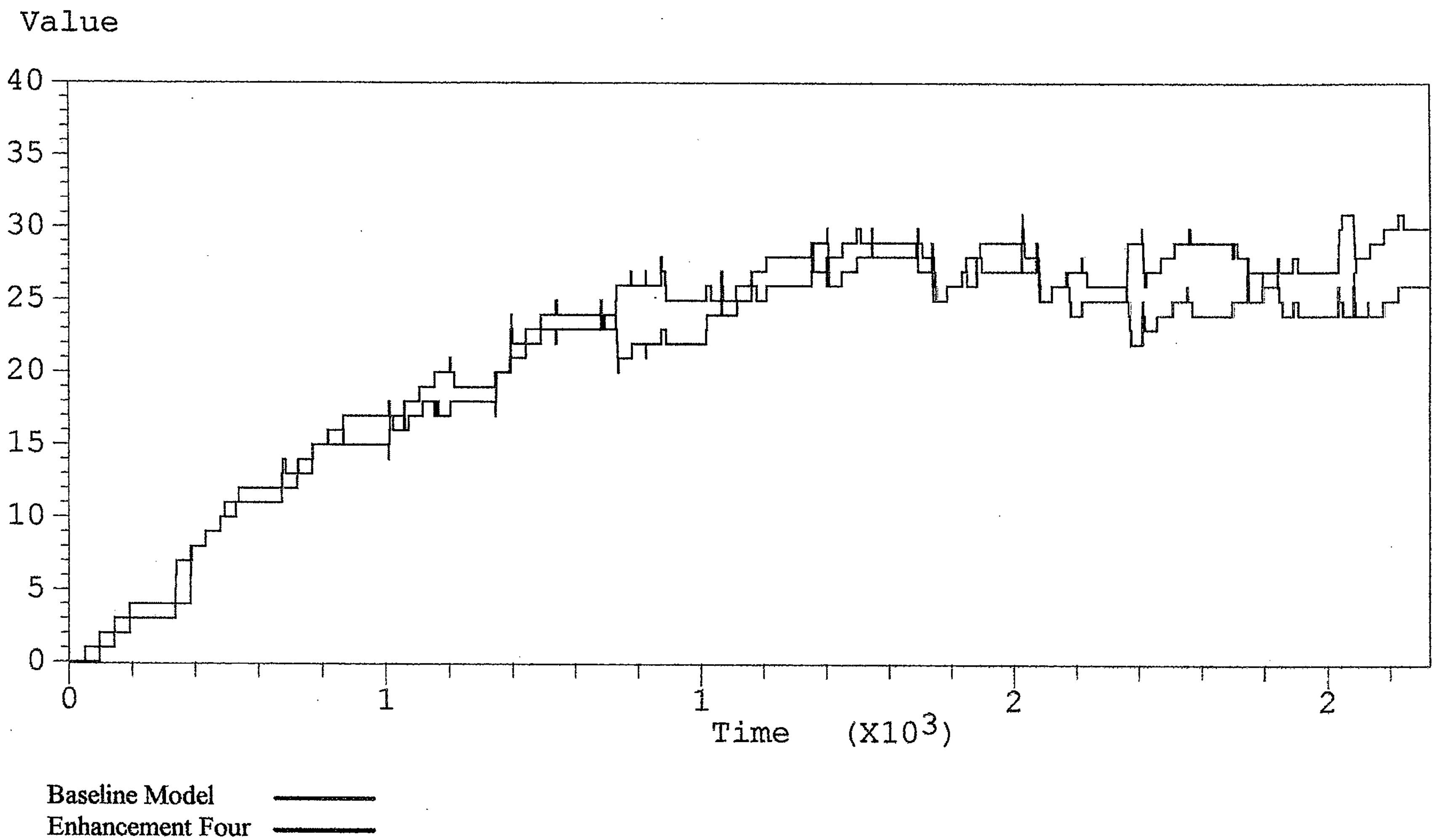


Baseline WIP vs. Enhancement Two WIP
Value
40
35
30
25
20
15
10
5
0
0
1
1
2
2
Time (X10^3)
Baseline Model
Enhancement Two

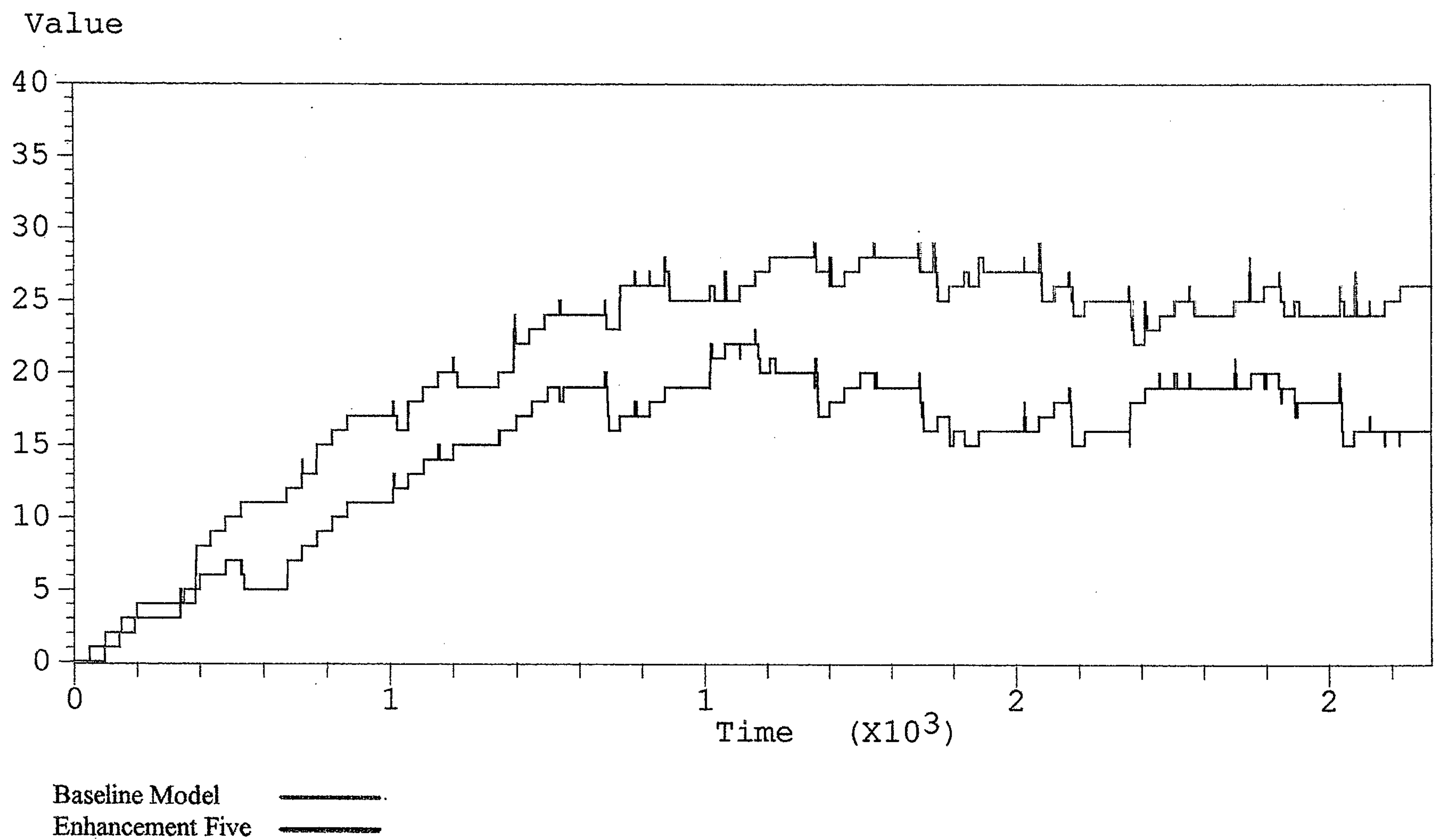
Baseline WIP vs. Enhancement Three WIP



Baseline WIP vs. Enhancement Four WIP



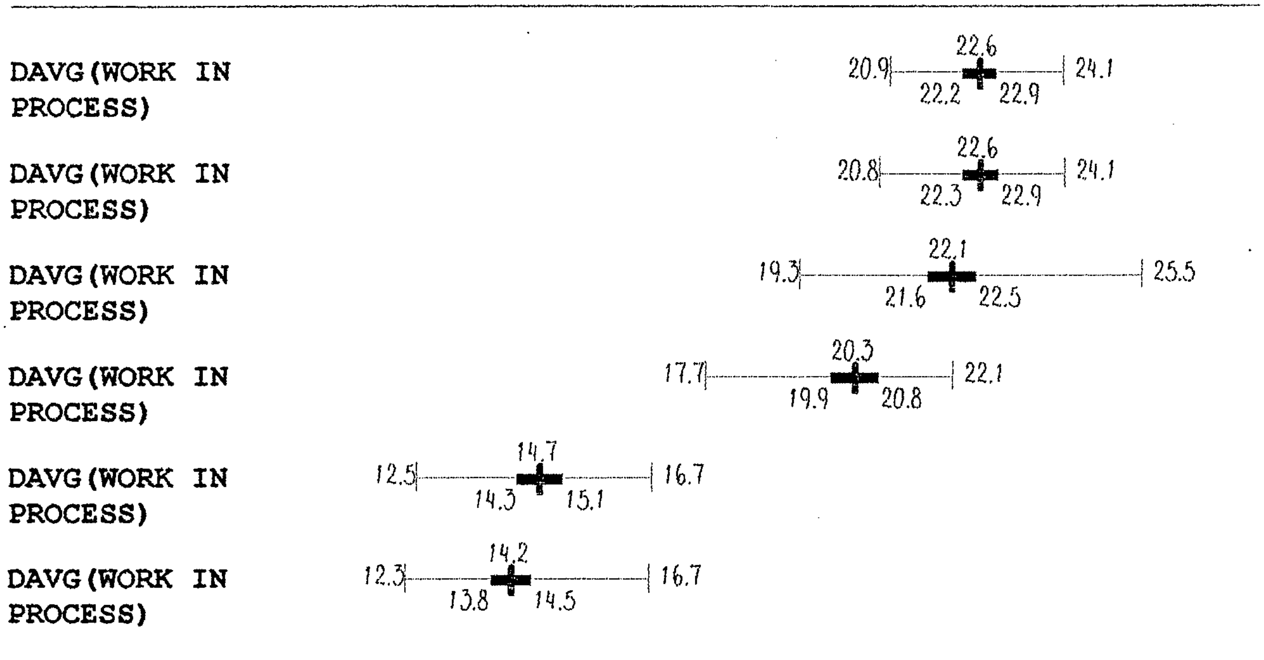
Baseline WIP vs. Enhancement Five WIP



Observation Intervals

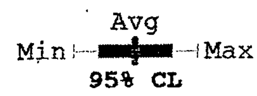
Average WIP 95 % Confidence Intervals

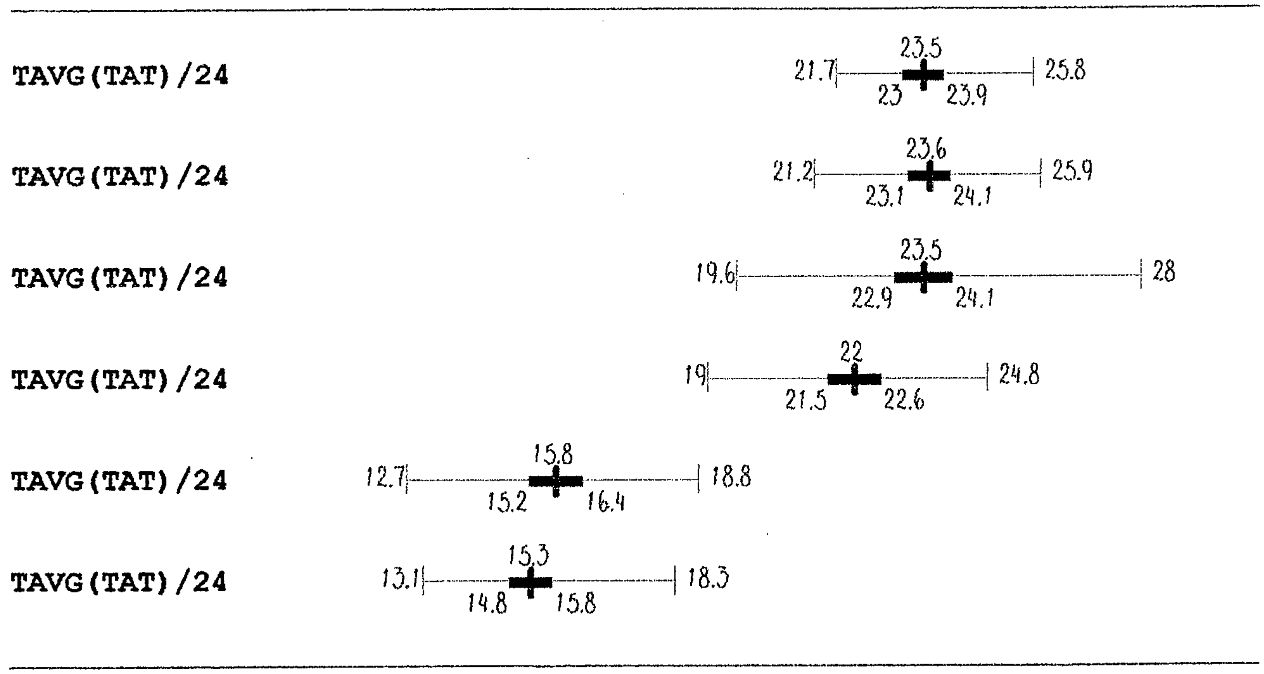
Avg
Min Max
95% CL



Observation Intervals

Average TAT 95 % Confidence Intervals





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Dr. Keebom Kang
Naval Postgraduate School
Department of Systems Management
411 Dyer Rd.
Monterey, CA 93943..1

Donald R. Eaton, RADM, USN (Ret.)
Naval Postgraduate School
Department of Systems Management
411 Dyer Rd.
Monterey, CA 93943..1

LCDR Kevin F. Mooney, SC, USN
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